MINUTES OF PROCEEDINGS

OF THE

INSTITUTION

OF

CIVIL ENGINEERS;

WITH

ABSTRACTS OF THE DISCUSSIONS.

VOL. XIX.

SESSION 1859-60.

EDITED BY
CHARLES MANBY, F.R.S., M. INST. C.E., HONORARY SECRETARY;
AND
JAMES FORREST, ASSOC. INST. C.E., SECRETARY.

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INSTITUTION

OF

CIVIL ENGINEERS.

SESSION 1359-60.

November 8, 1859.

JOSEPH LOCKE, M.P., President,
in the Chair.

At the commencement of the proceedings, Mr. Locke, M.P., —President,—thus addressed the Meeting:—

Gentlemen,

I cannot permit the occasion of opening a new Session to pass, without alluding to the irreparable loss which the Institution has sustained, by the death, during the recess, of two most honoured and distinguished Members.

In the midst of difficulties of no ordinary kind, with an ardour rarely equalled, and an application both of body and mind almost beyond the limit of physical endurance; in the full pursuit of a great and cherished idea, Brunel was suddenly struck down, before he had accomplished the task which his daring genius had set before him.

Following in the footsteps of his distinguished parent, Sir Isambard Brunel, his early career, even from its commencement, was remarkable for originality in the conception of the works confided to him. As his experience increased, his confidence in his own powers augmented; and the Great Western Railway, with its broad-gauge line, its colossal engines, its large carriages, and its bold designs of every description, was carried onward, till it ultimately embraced a wide district of country. The same feeling induced him, in steam navigation, to construct the 'Great Western,' the largest steamer of the time, afterwards surpassed by the 'Great Britain,' to be, in its turn, eclipsed by the 'Great Eastern,' the most gigantic experiment of the age. This 'Great Ship' was Brunel's peculiar child: he applied himself to it in a manner which could not fail to command respect; and if he did not live to see

its final and successful completion, he saw enough, in his later hours, to sustain him in the belief, that his 'idea' would, ultimately, become a triumphant reality.

The shock which the loss of Brunel created, was yet scarcely thoroughly felt, when we were startled by the announcement, that another of our esteemed Members had been taken from us.

Of that friend, I feel it to be a difficult task to speak, without giving way to feelings better fitted for the closet than a public assembly. ROBERT STEPHENSON was the friend of my youth, the companion of my ripening years, a competitor in the race of life; and he was as generous as a competitor, as he was firm and faithful as a friend. This will, I know, find an echo in the hearts of all around me; and your feelings will supply that laudation, in which it would seem inappropriate for me to indulge.

Like Brunel, Robert Stephenson commenced his professional career under his Father, George Stephenson. His early years were devoted to the improvement and construction of the Locomotive Engine, and to him we owe the type of those machines, many of which are now actually in use on railways. From the time of the Liverpool and Manchester Railway, when our joint Report contributed, in a great degree, to the adoption of the Locomotive Engine as the means of transport, and of the subsequent London and Birmingham Line, with its long Parliamentary contests, its Kilsby Tunnel, and other difficulties inherent in so new an undertaking, a multitude of other lines followed, in which there had to be foreseen and provided for, numerous difficulties, all of which were met and surmounted with coolness and consummate skill. Among these great works may be mentioned the Royal Border and High Level Bridges, and more especially, the Conway and Britannia Bridges, which were the first examples, on so vast a scale, of the Tubular principle, invented by him; as also the Bridges across the St. Lawrence and the Nile, remarkable alike for their grandeur of conception and successful execution.

To my present hearers, the enumeration of the works in which Robert Stephenson was engaged would be as a "twice-told tale." Still we cannot look back without interest upon the days of the 'Battle of the Gauges,'—the discussions upon the Atmospheric System,—and the numerous topics which have been argued within and beyond these walls.

In the enjoyment of a distinguished name and reputation, Robert Stephenson, like Brunel, has been cut off while still in the middle period of life; and although he pursued his profession with persevering energy, although he accomplished in it those triumphs of the successful application of a mind well trained and stored with practical and theoretical knowledge of various kinds, and achieved

some of the greatest works of art which have been witnessed in our day, he obtained, at the same time, an eminence in the scientific world rarely reached by any practical professional man.

It is not my intention, at this moment, to give even an outline of the works achieved by our two departed friends. Their lives and labours, however, are before us, and it will be our own fault if we fail to draw from them useful lessons for future guidance. Man is not perfect, and it is not to be expected, that he should be always successful; and as, in the midst of success, we sometimes learn great truths before unknown to us, so also we often discover, in failure, the causes which frustrate our best directed efforts. Our two friends may probably form no exception to the general rule; but judging by the position they had each secured, and by the universal respect and sympathy which the public has manifested for their loss, and remembering the brilliant ingenuity of argument, as well as the more homely appeals to their own long experience often heard in this hall, we are well assured, that they have not laboured in vain. We, at least, who are benefited by their successes, who feel that our Institution has reason to be proud of its association with such names as BRUNEL and STEPHENSON, have a duty to perform, and that duty is to honour their memory and to emulate their example.

I ought to add, in conclusion, that amongst the many private and public bequests made by Robert Stephenson, is one to this Institution, of the munificent sum of Two Thousand Pounds.

No. 1,000.—"On the Process of Raising and Hanging the Bells, in the Clock Tower, at the New Palace, Westminster." By JABEZ JAMES, Assoc. Inst. C.E.

THE subject of lifting heavy weights and of moving huge masses has occupied the attention, and brought forth the inventive genius, of practical men, both in ancient and modern times; and though few, or no records remain of the methods employed in moving the masses piled up in the days of antiquity, it is evident, that if the ancients were not acquainted with the use of mechanical appliances, they possessed, at least, a knowledge of the means of combining human forces, unknown at the present day. The results they obtained are, however, thrown into the shade by the purely mechanical operations now in use, by which such masses as the tubes of the Britannia and of the Saltash Bridges are raised with certainty and facility. Feeling it to be incumbent upon all to record the means of successfully accomplishing any work, however unimportant, these brief particulars, relative to the hoisting of the great bell,

and four quarter-bells, to the chamber at the top of the Clock Tower, at the New Palace of Westminster, have been compiled, not for the purpose of comparing the operation with greater works, but with the intention of supplying an additional link in connection with works of a similar character; and as locality, and description of material, as well as the available means for its execution, must, at all times, materially affect the arrangements for such an undertaking, it is presumed, that the Paper may not be wholly uninteresting.

From the papers and correspondence relating to the clock and bells, ordered by the House of Commons, it appears, that the connection of Mr. E. B. Denison, Q.C., with the bells, commenced about the beginning of the year 1855. Sir Charles Barry, who had been applied to on the subject by the Secretary of the Commissioners of Works, recommended, that a specification should be drawn up by Mr. Denison, who was more particularly competent, not only from his knowledge of the manufacture and requisites of bells, but also from his having designed and superintended the construction of the clock; and that, in the selection of the metal to be employed, he should be associated with the Rev. W. Taylor, F.R.S., who had devoted much time and attention to the construction of bells. He further recommended, that if the Board should determine to adopt the principle of competition, application should be made to four bell-founders; Messrs. Mears, Messrs. Warner and Sons, Messrs. Taylor and Son of Loughborough, and Mr. John Murphy of Dublin: but if the commission should be given at once, he thought it would be advisable to intrust its execution to the first-mentioned firm. Mr. Denison, accordingly, at the request of the Commissioners, sent in a specification with a list of all the founders in England who had cast large bells, to whom it should be submitted for tender, but especially recommending Messrs. Warner and Sons, who, at the suggestion of Mr. Taylor and himself, had recently undertaken a series of experiments, in order to arrive at the best form and thickness for large bells. Subsequently, in consequence of Mr. Denison's refusal to admit the Chief Commissioner of Works as a third referee, his services were declined. A further correspondence ensued between the Secretary, Professor Wheatstone, and Sir Charles Barry, "in regard to the size, weight, and shape which should be adopted in the construction of these bells," which resulted in the Commissioners requesting those gentlemen "to collect information respecting the most esteemed chimes in France and Belgium, and whether there are, in either of those countries, makers acquainted with the traditions of the art, or who have applied the modern discoveries of science to the improvement of bells, or to efficient substitutes for them."

When Sir Benjamin Hall became Chief Commissioner, on the death of Sir William Molesworth, he consented to the terms proposed by Mr. Denison, and a specification for supplying the five bells was, eventually, issued, from which the following is an extract:—

"The fifth, or hour-bell, is to weigh 14 tons, as nearly as possible, and the quarter-bells are to be of such notes, that they would be, respectively, the first, second, third, and sixth, of a peal of ten, the hour-bell being the tenth; they are to be fitted to stocks of such size and in such manner as may be approved by the referees, or any two of them; but they will not be required to swing, and are, therefore, not to have gudgeons. They are each to be furnished with a clapper, and a fixed pulley, or a crank, so that they may be rung with a rope on occasions, if required. As it is understood not to be possible to calculate exactly the weight of the bells before they are cast, the tender is to state at how much per cwt. you will supply them, and also your estimate of the probable weight of the several quarter-bells, assuming the great bell to be 14 tons, with a separate item for the cost of the fittings and delivery at the Clock Tower of the Houses of Parliament, and the time at which you will engage to deliver them. The whole of the work is to be done under the directions of Edmund Beckett Denison, Esq., one of her Majesty's Counsel, the Rev. William Taylor, F.R.S., of 73 Oxford Terrace, and Professor Wheatstone, of King's College, London, or any two of them, and payment is not to be made until they, or two of them, have certified their final approval of the bells, after they are hung in the tower. The tender is also to state for what sum you will undertake to raise and hang the bells. All the bells, except the great one, can be taken up inside the tower; the great one is too large for the space left clear inside, and must be taken up outside. There will be no framework to provide, as the top of the tower will be built with the requisite beams, or supports to carry the stocks. The Commissioners reserve the right to get the bells raised and fixed by the builders, if they find, that it can be done more cheaply by them, by means of the tackle now in the tower belonging to them." This tender was prepared, mainly, from the form furnished by Mr. Denison and forwarded by him to the Secretary of the Commissioners of Works, on the 30th of February, 1855.

It may be here noticed, that Mr. Denison, in his work upon Clocks, Watches, and Bells, says, in alluding to the Westminster great bell:—"but for the alteration made by Mr. Denison in the usual shape of the bell, a bell of 14 tons could not have been taken up between the walls."

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[1] *Vide* "A Rudimentary Treatise on Clocks, Watches, and Bells, with a full account of the Westminster Clock and Bell." By E. B. Denison, M.A., Q.C. Page 106.

The first large bell, which weighed 15 tons 18 cwt. 1 qr. 22 lbs., was cast by Messrs. Warner and Sons, the successful competitors, at Norton, near Stockton-on-Tees; it was brought by sea to Messrs. Maudslay's wharf, Lambeth, where it was landed, on the 30th of October, 1856, and was immediately afterwards conveyed in a truck to the base of the clock tower, where it was lifted from the carriage by means of a double-purchase crab, and suspended from a staging, erected especially for the purpose of making various experiments on the tone of the bell. This bell was subsequently ascertained to be fractured, and was, therefore, condemned on the 24th of October, 1857. The fracture took place on the opposite side from where it was struck by the clapper, which weighed 12 cwt. The fracture passed from the lip, through the sound bow, and extended up the waist of the bell, and was about 40 inches in length. It appeared clean, but the metal had a coarse dull appearance, and was full of very minute holes, which were noticed on other parts of the bell, when it was afterwards broken up. The operation of breaking up the bell was commenced on the 16th of February, 1858, and lasted about five days, when it was removed for the purpose of being recast.

The second large bell, which weighed 13 tons 10 cwt. 3 qrs. 15 lbs., was cast, at Whitechapel, by Messrs. Mears, after competition, by tender, with Messrs. Warner and Sons, and was received on the 5th of May, 1858, at the New Palace, where, like the former bell, it was suspended from the same staging, in order to undergo certain tests.

The four quarter-bells, cast by Messrs. Warner and Co., were delivered at the clock tower on the 18th of June, 1858, and were hung at equal distances round the large bell, for the convenience of sounding, &c. In consequence of the third quarter-bell being condemned, as defective, it was removed to be recast. The new bell was received on the 10th of September, 1858, and all the bells were sounded, and otherwise experimented upon, by Mr. E. B. Denison, and the Rev. W. Taylor, on the 22nd of the same month.

The hoisting of the bells to the bell chamber was immediately commenced. The first quarter-bell, weighing 1 ton 1 cwt. 0 qr. 23 lbs., was lifted on the 23rd of September, in three hours; the second quarter-bell, weighing 1 ton 5 cwts. 1 qr. 2 lbs., on the 24th, in three hours and a half; and the third quarter-bell, weighing 1 ton 13 cwt. 2 qrs. 13 lbs., on the 26th, in four hours. These three bells were raised by means of a double-purchase crab, with a single chain, made of rod iron, $\frac{7}{8}$ths of an inch in diameter. The fourth quarter-bell weighing 3 tons 17 cwt. 2 qrs. 13 lbs., was raised in six hours, on the 30th of September, by a double chain of the same diameter, in a similar manner.

When instructions were given by Sir Charles Barry, the archi-

tect of the New Palace, to carefully consider the best method for raising the large bell to its permanent position in the bell chamber, he expressed an earnest wish, that all due economy should be observed, while, at the same time, he desired, that every attention should be given to insure the safe accomplishment of the undertaking. After some consideration of the usual methods adopted for raising heavy weights, Mr. Quarm, the clerk of the works, decided, in conjunction with Mr. James, that a crab, with blocks and a fall, would be the most economical, safe, and efficient plan; and it was thought, that by making some alterations to a crab on the works, in order to give it additional power, so as to convert it into a treble-purchase crab, it would, with some large blocks, be sufficient for the purpose. A new chain-fall which could be relied upon, was manufactured by Messrs. Hawks, Crawshay, and Co.; it was a chain $\frac{7}{8}$ths of an inch in diameter and 1,500 feet in length, made of the best cable bolt iron, and was proved to a strain of 10 tons. This chain was reeved through two three-sheaved blocks, so that the weight of the bell would be distributed over the several multiples of the chain, according to the number of reevings. This, with a standing chain, gave a power equal to about 70 tons according to the proving strain; the breaking strain of a single chain being about $13\frac{3}{4}$ tons, according to the navy proof. The bell was 9 feet in diameter at the sound bow, and 7 feet $10\frac{1}{2}$ inches in height, and the tower shaft, up which it was to pass, was only 8 feet 6 inches by 11 feet 1 inch; it was not, therefore, possible to lift it by its crown and with its mouth downwards; consequently, it became necessary to construct a cradle in which it should rest on its side.

This cradle, (Plate 1., Figs. 4, 5, 6, and 7,) was composed of strong timber, well bolted and tied together. The bell was then lifted into the cradle and securely packed and made fast in every direction, (Figs. 6 and 7,) in order to prevent its slipping. Two friction rollers were attached to the cradle at the top, and two at the bottom of each of the four uprights; and four lengths of timber were bolted to the shaft from the bottom to the top, forming guides, (Figs. 4 and 5,) for the rollers to rub against. This precaution was necessary, in consequence of the great and unequal weight at the sound bow, rendering it impracticable to suspend the bell with the cradle, from the centre; the centre of gravity having to be found by the appliances of short lifts, and the adjustment of the clip and shackle. A flitch beam with two plates 22 inches wide, 14 feet long, and $\frac{3}{4}$ths of an inch thick, was securely fixed between six timbers, to which the upper block was made fast by means of a shackle and clip, the lower block being attached with a shackle and clip, to an oak beam firmly secured to the cradle, by massive bolts and straps. The treble-purchase crab, already alluded to, was fixed on a strong staging in the cast-iron lantern

at the top of the tower, in such a position as to leave a distance of about 19 feet between the bottom of the crab and the crown of the bell, when the latter was raised to its proper position. It was impossible, that the single barrel of the crab could take up all the chain, without incurring the risk of surging, consequent upon the coiling of the chain in so many thicknesses. It was important to avoid this, particularly as the bell had to be raised up a dark shaft of very restricted dimensions, where the cradle and bell could not be seen after being raised about 12 feet from the base of the tower, until it was landed in the clock room; several lifts were, therefore, made, as described in the tabular statement given in the Appendix, (page 12), wherein is also registered the time occupied for each lift and for the fleeting of the chain.

An iron chain-stopper of a special construction was made, for the purpose of holding the chain, during the fleeting, on the drum of the crab. This stopper was made of two pieces of wrought iron, shaped and recessed at the meeting parts, to receive three, or four links of the leading chain. These halves being bolted together, formed, as it were, one solid block of iron, with the chain held fast in the centre. The stopper was wedged-up on two stout timbers, placed upon each side of the leading chain, and the weight was then removed from the crab and taken up by the stopper, the the chain being, at the same time, fleeted to the other end of the drum of the crab, ready for a fresh lift; the stopper was then removed, until another fleeting took place, when the same operation was repeated. An ordinary chain-stopper might have been used for this purpose, but it was considered, that it would not be so efficient. The slack was taken off the large crab, by means of another chain-fall from a purchase crab fixed in the clock room, so that, in the event of any accident occurring to the slack part of the chain, it would be held by the back crab. The weight of the bell, with the cradle and ironwork, together with the chain, blocks, &c., was about 25 tons, exclusive of friction. The whole of the arrangements made in the tower for lifting the bell, is shown in Fig 2.

The process of hoisting commenced at six o'clock on the morning of the 13th of October, and was continued without intermission, until noon of the following day, when the bell was safely landed on a staging in the clock room. The cradle was then disconnected, and the bell was turned over, (Fig. 8,) with the crown upwards. An eye-bolt was passed through, and being now clear of the shaft, the bell was lifted in the usual way, from the clock room to the bell chamber, on the 20th of October. It was raised a total height of 201 feet $3\frac{1}{4}$ inches, at an average velocity of about 6 feet 5 inches per hour, as shown in the Appendix, and securely packed up in its proper position, upon timbers

placed across the shaft through which the bell had ascended. Before the bell could be permanently fixed, certain works had to be executed; the whole of the staging, the crab, and the other apparatus employed in lifting, had to be removed, and the cross tubular beam to which the bell was to be suspended, had to be fixed and riveted in its place. It was not before the 11th of November, 1858, that the bell was suspended to the carriage, prepared to receive it and its four quarter-bells. This carriage, (Fig. 3,) was formed of twelve cast-iron standards, three on each side of the tower, their ends resting in cast-iron shoes, securely tied by tension rods and couplings, crossing from one side of the tower to the other, and around the walls. The standards carried a square framework of wrought-iron girders, riveted together at the angles, and braced by angle brackets to standards; india-rubber pads being placed between the standards and the girders, and rollers under the cast-iron shoes, to prevent any vibratory disturbance to the outer walls of the tower, and to allow for expansion, or contraction. The four quarter-bells were suspended, in a similar manner, from four diagonal wrought-iron girders, riveted at each angle to the framework of the carriage. The arrangements made for hanging the bells in the tower, are shown in Fig. 1.

Steam power had been applied in raising to a height of about 160 feet on the Victoria Tower, some cast-iron girders, each 12 tons in weight, which required to be all dropped into their places together. An undulating motion was, however, observed to have been produced through the beat of the valve; consequently, that mode of raising the bell was considered objectionable, as not being sufficiently steady, taking also into account the narrow aperture through which it had to pass, and the manner in which it was obliged to be slung; manual labour was, therefore, adopted.

The first experiment upon the bells took place with the clapper, on the 18th of November, when Mr. Denison ordered a temporary hammer to be made, weighing 3 cwts. 1 qr. 12 lbs., and six shifting pieces, weighing 38 lbs. each, so as to ascertain the right weight and proper fall of the hammer necessary to bring out the full sound of the bell, which was rigidly bolted up to the girders, with a gasket packing placed between them and the bell. Previous to the second experiment, which was made by Mr. Denison on the 25th of November, Mr. Quarm, on his own responsibility and unknown to Mr. Denison, ordered the bolts to be slackened. Mr. Denison was surprised at the effect, and he was then informed by Mr. Quarm, that he had reduced the fall of the hammer to 8 inches. This amount of fall not proving satisfactory, a third experiment was made with a hammer lifting 20 inches and weighing 5 cwts. 1 qr. 16 lbs., on the 29th of November,

when Mr. Denison ordered the weight of the hammer to be increased. A fourth experiment was, therefore, made on the 1st of December, with a hammer weighing 6 cwts. 3 qrs. 10 lbs., and with a fall of 13 inches. Mr. Denison then decided, that such should be the permanent arrangement for striking the hours; it was, accordingly, carried out, and continued in operation until the 29th of September, 1859, when the bell was discovered to be fractured in two places. One of the cracks is precisely in the same position in this bell, as the fracture in the former one,—exactly opposite to the place where it was struck by the hammer,—the other being at a distance of about 2 feet from the first. The first fracture is 15 inches in length, and the second, about 24 inches, but at present, it does not extend through the thickness of the bell, nor within 2 inches, or 3 inches of the lip.

The hammer of the first quarter-bell weighs 56 lbs. and falls 7 inches; that of the second weighs 60 lbs. and falls 8 inches; that of the third weighs 80 lbs. and falls 9 inches; and that of the fourth weighs 200 lbs. and falls 10 inches. These weights are exclusive of the weight of the levers.

The whole of the works were carried out by Mr. Henry Hart, assistant to Mr. Jabez James, under the personal superintendence of Mr. Thomas Quarm, clerk of the works.

The Author believes, that the following information, for which he is indebted to the Rev. W. Taylor, F.R.S., will not be without interest, as affording means of comparing the Westminster Bell with the other large bells of Europe.

The great bell at Lucerne, which is slightly ornamented, is 7 feet 11 inches in diameter, 6 feet 1 inch in height, and about 8 inches thick, the ball of the clapper being about 1 foot in diameter. These dimensions must be considered as only approximative, as he had no instruments for measuring them. The bell, which was cast in 1636, and weighs $5\frac{1}{2}$ tons, is rather narrow in the waist and thin towards the top, and has been turned twice, to enable the clapper to strike in a different place. It has no wheel, and it swings in an arc of only about 100°. Being struck about half-way up, it gives a note as good, nearly, as when struck in the proper place, but a fourth higher. A priest of the cathedral stated, that when the bell was new, the note was A, but that now it is, according to the present pitch, A ♭. This would show the pitch to have risen half a note; but by Mr. Taylor's fork, the note was B ♭.

The great bell at Cologne is 7 feet $10\frac{3}{4}$ inches in diameter at the skirt, 6 feet 2 inches high, and, so far as he could judge, $9\frac{3}{4}$ inches thick at the sound bow. The circumference of the ball at the clapper is 2 feet $10\frac{1}{2}$ inches; the stock is 19 inches in depth and 13 inches thick. The bell requires ten men to swing it

in an arc of about 150°. The weight is about 11 tons, or a little more. It is not ornamented, and looks rather thick in the waist: it has not a complete wheel. The note is G, rather flat. It hangs in a frame of wood, inside the stone walls of the tower, at about 140 feet, or 150 feet above the ground. This wooden frame rests upon a projecting part of the wall, about 10 feet from the ground.

The great bell in the church of St. Gudule, at Brussels, which dates from the year 1481, is 7 feet 1½ inch in diameter at the skirt, 3 feet 4½ inches in diameter at the top, and 5 feet 6 inches in height. It weighs nearly 6 tons, and it is rather cylindrical in the waist. It is hung below the stock, fastened to a piece of wood 12 inches beneath. It is not rung by ropes, but by eight men treading alternately on the ends of boards, placed transversely upon the stock. The note is G, or G♯. All these bells have excellent tones, especially that at Cologne, which, when swinging, seems to fill the whole town with a deep, full, and musical sound.

According to Otte, a German author, the great bell of Moscow weighs 144,000 lbs., is 18 feet in circumference, and 21 feet in height; the clapper weighs 4,200 lbs. This bell, which is much ornamented, was cast in 1817.

The largest bell ever cast, called Isar Kolokot, weighs 400,000 lbs.; it is 22 feet 5⅓ inches in diameter, 21 feet 4½ inches in height, and its greatest thickness is 25 inches; the ball of the clapper is 6 feet in circumference. This bell, which is much ornamented, was cast in 1734; but being broken immediately afterwards, it was left on the ground till 1837, when the Emperor Nicholas caused it to be placed upon a pedestal, or block of masonry.

The great bell at Erfurt was cast in 1497, by Gerhard Von de Campis, and is called Maria Gloriosa. It weighs 252 cwt., or, as is now thought, 276 cwt.; it is 8¼ Rhenish feet in diameter, 6⅞ feet in height, and 8¼ inches thick at the sound bow. On the crown are seven ears, each weighing 1 cwt., by which it is suspended; the clapper weighs 11 cwt. Sixteen men ring it by means of four ropes, which divide at the bottom into four others; but when rung 'up to set,' it took twenty-eight men. In favourable winds, it is heard well at a distance of fourteen English miles. The note is E.

The great bell of St. Peter's, at York, weighs about 10½ tons. It never has yet been rung 'up to set,' although thirty-six men have tried to raise it.

The usual proportion of metal in the Continental bells is 4 parts of copper to 1 part of tin.

The Paper is illustrated with a series of diagrams, from which Plate 1, (Figs. 1 to 7,) has been compiled.

[APPENDIX.

APPENDIX.

The Raising of the Great Bell, which was at the height of 2 feet 8½ inches from the ground, was commenced at the NEW PALACE, WESTMINSTER, at Six o'clock, A.M., on the 13th of October, 1858, and continued until noon of the following day.

No. of Fleets.	Periods of Fleeting.		Time employed in Raising.		Height Raised.		Total.	
No.	h.	m.	h.	m.	ft.	in.	ft.	in.
1	7	0 A. M.	1	0	6	10	6	10
2	8	30	1	30	6	10	13	8
3	9	45	1	15	6	10	20	6
4	11	15	1	30	6	10	27	4
5	12	45 P. M.	1	30	6	10	34	2
6	2	15	1	30	6	10	41	0
7	3	30	1	15	6	10	47	10
8	4	55	1	25	6	10	54	8
9	6	18	1	23	6	8	61	4
10	7	47	1	29	6	10	68	2
11	9	21	1	34	6	10	75	0
12	10	54	1	33	6	11½	81	11½
13	12	20 A. M.	1	26	6	11	88	10½
14	1	47	1	27	6	9½	95	8
15	3	17	1	30	6	11	102	7
16	4	14	0	57	6	9¾	109	4¾
17	5	0	0	46	6	10¾	116	3½
18	5	40	0	40	6	11	123	2½
19	6	17	0	37	6	11	130	1½
20	7	3	0	46	6	8	136	9½
21	7	50	0	47	6	8	143	5½
22	8	40	0	50	6	9½	150	3
23	9	18	0	38	6	10½	157	1½
24	10	5	0	47	6	10	163	11½
25	10	40	0	35	6	9½	170	9
26	11	10	0	30	5	0	175	9

It was again raised from the Clock Room to the Bell Chamber, at a Quarter past Nine o'clock, A.M., on the 20th of October, 1858.

No. of Fleets.	Periods of Fleeting.		Time employed in Raising.		Height Raised.		Total.	
No.	h.	m. A.M.	h.	m.	ft.	in.	ft.	in.
1	9	45	0	30	7	0	182	9
2	10	27	0	42	6	9	189	6
3	11	5	0	38	6	10½	196	4½
4	11	25	0	20	2	2¼	198	6¾
Height raised as above							198	6¾
Add height from the ground, at the commencement							2	8½
Total height . . .							201	3¼

[MR. ARTHUR FRY

Fig. 2.

Mr. ARTHUR FRY[1] said, he was not practically acquainted with the art of bell-founding; he could only inform the Meeting, that Messrs. Warner and Sons attributed the fracture of their bell, to the enormous weight of the hammers with which it had been struck.

Mr. QUARM had noticed, at various times, in the striking of the present large bell, a difference of sound. When the hammer did not rest upon the bell after the blow, the sound was good and clear; but if the hammer was not immediately recovered by the recoiling apparatus, and was thus allowed to rest on the bell, it produced a chattering and a numbness in the sound which impeded the vibrations, and, to use the technical expression, 'stunned' the bell. The Rev. W. Taylor, he believed, was also of opinion, that the chattering of the hammer upon a bell operated most prejudicially upon the sound, as well as upon the bell itself. If a bell was fairly struck with a hammer of a moderate size, the weight was not of much importance; but if the hammer was allowed to rest on the bell after the stroke, it would, sooner, or later, destroy it. The effect of an ordinary clapper striking a bell, was very different from that produced by the whole force of the weight of a clock hammer. The weight of an ordinary clapper resting, after the blow, on the side of the bell, when it was in the act of turning, with its mouth upwards, was very different to that of a hammer weighing 7 cwt., striking with all its force of gravity, upon the outside of the bell, when in a comparatively rigid state. He was opposed to the opinion, that the resting of the hammer upon the bell, and the defective arrangement of the apparatus for striking, had not materially conduced to the fracture of the bell. He attributed the fracture of the first bell, to the excessive weight of the clapper used in making the experiments, and the enormous power required in pulling it, eight men having been so employed under Mr. Denison's direction.

Mr. CHARLES MAY observed, that the first bell was struck by a blow from the inside; the fracture, consequently, could not have been due to chattering. He was present at the experiments upon the first bell, and he heard it crack very distinctly; he mentioned it at the time the blow was struck, and the fact was soon afterwards verified. He believed the fracture to have been due to the hardness of the composition employed in the manufacture; for no large bell with so great a proportion of tin, could possibly resist a succession of heavy blows. The clapper, which weighed 12 cwt., was a mass of wrought iron of an elliptical section. He measured

[1] Mr. Loseby, at the commencement of the discussion, offered some remarks on the subject, but as they have been already published in several scientific periodicals, they are, by the Bye-Laws, Section xiv., clause 3, precluded from appearing in the Minutes of Proceedings.

the extent of the impression which had been made upon the wrought-iron clapper, and found it to be about 4 inches long and $2\frac{1}{4}$ inches wide. There was not any visible impression upon the inside of the bell, the metal of which was, consequently, harder than wrought iron. He thought the designer of that bell could have known little, or nothing of the alloys of tin and copper, or he never would have adopted those proportions. With but a very slight increase of tin, the result was a composition more brittle than glass. He had no doubt, that the defective quality of the bell, had arisen from its thickness, and the too great proportion of tin. He could not venture to say, whether such a mass of metal could be made by a very long process of annealing. In Mr. Mallet's work on Artillery,[1] a list was given of the atomic proportions of different alloys of copper and tin. In weight, 6 atoms of copper to 1 of tin were in the proportion of 76·29 to 23·71. The metal used in the composition of the bell, was in the proportion of 76·29 parts of copper to 24·27 parts of tin, or about 2 per cent. more tin. If the above-named atomic proportion was aimed at, the quantity of tin was nearly right, as this metal was apt to diminish in melting more than the copper; but Mr. Mallet put its specific gravity at 8·75, whereas that specified in the contract was 8·9. Mr. Mallet marked this alloy as 'brittle.'

Mr. QUARM stated, that the first bell had been also frequently struck on the outside by a hammer weighing 12 cwt., and that the proportions of the metals were the same in both bells. He did not attribute the failure of the bell exclusively to the chattering. The metal was excessively hard, and required a powerful blow to produce the sound. This hardness, and the brittleness due to the too great proportion of tin in the composition of the bell, combined with the weight of the hammer employed for striking it, and the defective apparatus used to take up the recoil of the hammer after the blow, were the causes of the fractures.

Mr. W. SMITH observed, that the Paper related only to the mechanical means employed to raise the bell to its position; but the discussion had turned upon the composition of the bell. He had been informed, that the proportions actually used were 7 parts of tin to 22 parts of copper; but it was desirable to have that fact stated authoritatively, as he had understood, that Mr. Denison did not recognise as authentic, any statements relative to the bells, or their casting, unless made by himself. It was also desirable to know, whether the contractors for the bells were permitted to make any variation from the specification supplied to them by Mr. Denison, in whom, he believed, was vested the entire responsibility.

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[1] *Vide* "On the Physical Conditions involved in the Construction of Artillery." 4to. By R. Mallet. London, 1856. Page 82.

Mr. Charles May said, there was no mention of the quality of copper used in these bells. It was well known, that Russian copper was charcoal-smelted, and so superior to any manufactured in England, that the Russian copper coinage was largely introduced into this country, for the use of certain classes of artists. He thought it probable, that most of the Continental bells were made of charcoal-smelted copper, which would give them greater toughness than those made of copper smelted by coke.

Mr. Bramwell inquired whether the metal of the first bell was used in casting the second bell; and if so, in what way the proportions were ascertained in the second casting; for he was not certain, that the same proportions of tin would remain, after repeated and long-continued fusion.

Mr. George Mears replied, that in accordance with the stipulations of the contract, the metal of the first bell was used in casting the second bell, with the addition of new metal made in the same proportions as before. The composition was limited to 22 parts of copper and 7 parts of tin, and the specific gravity to 8·9, from which no variation was permitted. The contract further provided, that the bell was not to be paid for, until Mr. Denison and the Rev. William Taylor had certified in writing to the First Commissioner, their approval of the bell, and that they were to be at liberty to reserve their certificate until the metal had been analysed. A piece was, accordingly, taken by Mr. Denison, for the purpose, as Mr. Mears was informed, of being analysed; after which, payment was made on the joint certificate of the referees.

Mr. Greaves remarked, that the lift of the hammer was stated to be 13 inches; but it did not appear whether that was a vertical motion, or a movement at some particular angle.

Mr. Pole said, that as the musical quality of the Westminster bells had been alluded to, he could state, that the lower, or B bell of the quarters, seemed imperfect; it gave the impression of being too flat in pitch, but the note was generally indistinct, and the tone disagreeable. The other three quarter-bells, E, F♯, and G♯, were better, and the chimes would, he conceived, have an agreeable effect, if the lower bell were perfect.

The great bell had a serious musical defect, as in addition to its principal note E, and the harmonics properly accompanying it, it sounded also a false note, not contained in the harmonic, or indeed in any musical scale; something between C♯ and D. This was very prominent, and the effect to those living near was excruciating, the defect in tone being universally complained of, even by those who were unable to define its musical nature. No such false note was observable in the first bell; and as the evil had

latterly, he believed, become worse, he was inclined to attribute it, either to the crack, which was understood to have existed some time before it was discovered, or to some injudicious mode of striking the bell.

Mr. SEWELL inquired whether bell-founders had turned their attention to the effects of the sound, or vibration waves caused by the heavy hammer, as the cause of fracture of the Westminster bells. From observations, some years ago, of the peculiar clean fractures of railway axles near the naves of the wheels, or at the angle of the bearings, he was led to the conclusion, that the granulated point of fracture coincided with the angular point where the concussive wave of vibration, arising from the impacts of the flanges of the wheels against the rails, would be arrested by the nave of the wheel, or the angle of the axle bearing. A similar conclusion was arrived at, in regard to the effects of the vibratory waves of expansion and contraction, in injuring the plates of boilers, at particular parts, where those waves were arrested by riveted joints, or angles, and he had stated those views in a Paper "On Steam Boiler Explosions," read, in 1854, by Mr. W. Fairbairn, (M. Inst. C.E.,) before the British Association at Manchester.[1]

"Some years since, the writer called the attention of a leading manufacturer of boiler plates to this description of plates, but some objections were urged as to the difficulty of rolling thick-edged plates, but it cannot be an insuperable one in these days of progress. Another source of injury to boilers, and one that is seldom noticed, is the liability of the plates being subjected to chisel cuts, and the joints to caulking-tool nicks. Experiments on the strength of iron have, in many instances, accidentally shown the decided loss of strength by abrasions of the surface so slight, that they were not detected until the early fracture of the iron showed their injurious effect, and ordinarily, little care is taken to avoid such abrasions of the surface in making boilers. With such cuts, or nicks at any part of a boiler, where the vibrations of contraction and expansion are arrested by any sudden change in the thickness, or the level of the surface, the fibrous structure of the iron is liable to slow, but certain injury. Analogous to this source of fracture are the numerous well-known instances, of railway axles breaking with more, or less depth of a crystalline appearance from the surface, but with the central portion fibrous. Much discussion has taken place on this apparent conversion of iron, originally fibrous, into a crystalline state, but it appears to the writer, that this conversion is strictly local, and confined to a sectional line, where some change of the diameter of the axle journal arrests the surface-wave of vibration, produced by the oscillation of the vehicle, so that a broken axle may exhibit a crystalline appearance at the fracture, and be quite fibrous on each side of that fracture. Generally, the fracture presents a worn appearance more, or less deep, next a crystalline aspect, whilst the centre shows the original fibrous structure of the axle. Incipient fracture had commenced at the surface, and attrition had afterwards worn it there, whilst the steadily deteriorating vibratory concussions were destroying the fibrous iron in the line of these concussions, until fracture took place under an

[1] *Vide* the "Mining Journal," 1854.

ordinary load, which had been safely carried many hundreds of times. It is well known to practical men, that fractures chiefly occur at the angle of the journal next the wheel, and appear to be due to the waves of vibration being arrested by these angular changes of the surface. The cohesion is ultimately injured there, beginning at the surface, and gradually deepening, therefore the time of fracture will be more, or less prolonged, according to the peculiar circumstance of each case. The crystallization is thus believed to be confined to the line of fracture, where contrary currents meet, or are arrested by irregularity of surface; and if this is a correct view of the cause of these axle fractures, it shows, that whenever iron has to sustain numerous constant vibrations, whether produced by motion as in railway axles, or by heat and pressure as in boilers, abrupt angles, or shoulders should be avoided, so far as it is practicable to do so"

On seeing the heavy hammer striking the first Westminster bell, suspended from a frame in New Palace Yard, and considering the probable effect of the meeting of the powerful waves of sound, or vibration thus produced, and passing round the bell in opposite directions, he had stated his belief, that it was only a question of time, how long the cohesive power of the bell metal would resist the granulating tendency of the meeting of these waves of vibration, before fracture would ultimately occur; and as anticipated, the first bell failed at a point almost immediately opposite the part struck, and the second bell had likewise failed by fracture opposite the point of impact of the heavy hammer against the bell. If, then, the conflict of the waves of sound, or vibration, set in motion by the blows of the heavy hammer tended to produce, first, a more granular structure of the metal, and, secondly, ultimate fracture, it would appear, that the power of cohesion was unequal to resist the vibrating power of disintegration, and that under such circumstances, fractures were only questions of time. If this view of the cause of the fractures of the bells was approximately correct, it followed, that cohesion to resist the vibrating force of such heavy blows, was an element to be duly considered in the composition of bells, as well as the proportion and thickness of metals to produce the required musical tones.

The meeting of opposite tidal, or river waves would illustrate, on a magnified scale, the meeting of the vibrations, or sound waves of bells, just as the force of a tidal wave against a wall, or rock, illustrated the effects of arresting the wave of concussion in railway axles, where pieces of iron even, of 3 inches and 4 inches in diameter, became quite granular at that part only, and fracture took place so frequently, as to lead to a change in the form and size of the axle bearings.

It appeared to him, that the fractures of the bells had arisen, from the cohesive power of the metals having been destroyed at the point of meeting of the opposite vibratory waves of sound, and that other bells similarly made and struck would share a similar

fate, unless the force of those vibrations could be lessened, or the cohesive force of the metal be sufficiently increased to successfully resist them, as in ordinary bells.

Mr. J. W. PAPWORTH said, that in old bells, such as the Bourdon, (1680,) of Notre Dame, at Paris, the clapper was frequently of harder material than the bell. On striking glass bells, which from their material were as good for experiment as metal bells, there was no difference of sound due to the greater, or less hardness of the clapper, which might be of metal, or of wood; the striking force, and not the hardness of the clapper, being productive of more, or less sound. The easiest way of breaking a glass bell was either to put something immoveable and hard, as small as a pin's point, against the bell opposite to the place where it was struck; or to give repeated blows, however light, with great rapidity. He suggested for consideration, whether the shortness of the interval between the blows, did not tend to cause fracture in metal bells. With regard to the composition of old bells abroad, he believed, that not only the Russian bells, but those of the Continent generally, contained other metals besides those of tin and copper, and that the point deserved consideration, although he admitted, that the quantity was very limited, perhaps so much so, that founders would probably think it too trivial to produce any result of practical importance. The treatment of copper by charcoal had, of course, been always and universally, the practice abroad.

Mr. CHARLES MAY suggested, that the experiment should be tried, of drilling a hole through the bell at the end of the crack. He had known that plan to have been followed with success, in bells of moderate size. Perhaps it might be found, as in the case of the last bell, that there was some extraordinary mistake as to its thickness. To ascertain the thickness of the first bell, recourse was had to drilling, whilst by the simple expedient of an inside and outside template, it might easily have been ascertained to the twentieth part of an inch.

Mr. JAMES said, in reply, that according to the best authorities, the proportions used in the German bells, were 80 parts of copper and 20 parts of tin. The vertical fall of the hammer last employed upon the Westminster bell was 10 inches, and the lineal movement 13 inches. He was present, on one occasion, with Mr. Denison at the foundry of Messrs. Mears, when an experiment was made upon three small bells of different alloy. The first, which contained no silver, broke into many pieces from a smart blow of a knife. The second, which contained silver to the extent of sixpence, broke after a certain number of blows; but the third, which contained a shilling, withstood the greatest number of blows, although it also, eventually, broke. He then suggested to Mr.

Denison, the propriety of making some alteration in the alloy of the great bell. He would add, that he thought the addition of silver to the alloy did not improve the sound of the bell, but it gave greater toughness to the metal.

The holes were drilled in the first bell by Mr. Denison's special order. With regard to the experiment suggested, he believed it to be useless, for if a bell was cracked, it would produce a different note, and in some cases, no correct note at all.

Mr. APPOLD believed the experiment of drilling would answer. He produced a small bell, which had been sawn through to the extent of $1\frac{1}{4}$ inch, yet it still sounded.

Mr. JOHN MURPHY,—through the Secretary,—stated, that in his early days, he had had considerable experience in the different qualities of copper. In a work of such vast importance as the great Westminster bell, the copper should be selected, and proved to be what is technically called 'tough copper,' bending easily, both when hot and cold. Bell and brass-founders, in general, paid little attention to this point, and were satisfied with what was termed 'made metal,' or metal made at other establishments to a certain consistency of temper. Although theorists were aware, that copper was the predominant metal in bells, they did not know the best proportions for producing a good tough bell, nor the quantity of granulated tin required to give to the metal a proper tenacity. Some founders did not use either granulated tin, or refined tin, but the common block tin. When granulated tin was used, with certain proportions of refined tin, and pure virgin copper, proper care being taken during the fusion, and every precaution used to insure a perfectly dry mould, a good sound bell must be the result. Another very important point in casting, but one often neglected, was to break away the solid core while still at a black red heat, to allow of the contraction consequent upon the cooling of the bell: this could easily be effected by mechanical appliances placed at the bottom; nor was there any danger to be apprehended, for red-hot bell-metal was as flexible as india-rubber. Bells had often been cracked, by allowing their cores to remain inside till they were cold. With respect to the shape of bells, the best rule for producing a good vibration was to make the width at the mouth, or widest part, double of that at the narrow part inside, close to the crown, and its perpendicular height inside, three-fourths of the diameter at the mouth. He would not recommend, that the material of the present bell should be employed in the recasting, as it would be too much impoverished by the frequent melting.

The bell constructed by himself, which was selected by Mr. Dent to strike the hours, in connection with his great clock in the centre of the hall of the Great Exhibition of 1851, was pur-

chased by the Great Northern Railway Company, and was now in use at King's Cross Station. It was composed of the purest copper, and of both refined and granulated tin, in certain proportions; its weight was about 28½ cwt. The diameter at the mouth, which was 4 feet 7 inches, was rather more than double the width at the upper part inside, and the perpendicular height was a little less than three-fourths of the widest diameter. The thickness of the sound bow was 3¾ inches. The note was D. The same note could be produced with 5 cwt. less of metal, but the bell would be weak and bad.

November 15, 1859.

GEORGE P. BIDDER, Vice-President, in the Chair.

No. 1,002.—"On the Government Waterworks in Trafalgar Square." [1] By CHARLES EDWARDS AMOS, M. Inst. C.E.

IN 1843, the Government, desiring to obtain a good supply of water for the fountains in Trafalgar Square, came to the conclusion, that the source suggested by Mr. James Easton was the most economical for the purpose, and determined, that his plan should be adopted. At that time, large sums of money were paid to the water companies for supplying the public offices, and Mr. Easton's scheme was so framed as to include the supply for those offices, as well as for the fountains.

The water was to be obtained and raised by engine power, from the springs beneath the London clay. The quantity of water required for condensing the steam of the engine, being too great to be taken from the main spring, it was considered expedient to use cooling ponds, and that a small quantity of water, in excess of that required for the public offices, should be taken from the springs, which, by running continually into the cooling ponds, would keep the water clean, and in a state fit for the purpose of condensation. The basins of the fountains were intended to form the cooling ponds. The water from them was to be taken for the use of the condenser, and afterwards raised into a cistern, whence it was to be conveyed to, and pass through the jets of the fountains, where, meeting with the resistance of the air, it would be partially cooled and be returned to the basin, for further circulation. Besides the quantity so taken for the use of the condenser, any further quantity could be raised from the basins by pumps, so that the supply to the fountains could be regulated to any extent that might be desired.

Data having been furnished as to the extent of the required water supply, estimates were given both for the erection of the works, and for the annual cost of working. It was found, that the yearly interest on the cost of erection, added to the cost of work-

[1] The discussion upon this Paper extended over portions of two evenings, but an abstract of the whole is given consecutively.

ing, would be less than the sum hitherto paid annually for the water supply to the public offices, and that, consequently, the playing of the fountains could be effected without cost to the Government. A contract was then made with Messrs. Easton and Amos for the whole of the works, which were commenced about the middle of January, 1844, a piece of ground having been selected in Orange Street, as a site for the steam engines. The first well was commenced at a level of 42 feet above Trinity high-water mark; it was of an oval form, 9 feet by 6 feet 10 inches, for a depth of about 15 feet, when it assumed a circular form to a depth of 174 feet from the surface. A cast-iron pipe, 15 inches in diameter, was then driven through 30 feet of plastic clay and to a further depth of 10 feet into a stratum of gravel, sand, and stones, and was left standing several feet in the well. Within this pipe, another, 7 inches in diameter was driven through 35 feet of green sand, and carried down 3 feet into the chalk formation, and the boring was then continued to the total depth of 300 feet from the surface.

The strata passed through were:—

	Feet.
Made earth	15
Gravel	5
Loam and gravel	10
London clay	145
Plastic clay	30
Gravel, sand, and stones	10
Green sand	35
Chalk	50
Total depth	300

A considerable quantity of water was obtained from the sand, by the 15-inch pipe, but the greater quantity came from the chalk, by the 7-inch pipe.

A second well was sunk in the inclosure immediately in front of the National Gallery, where the surface was 28·83 feet above Trinity high-water mark. This well, which was 4 feet 6 inches in diameter, was carried down 3 feet into the plastic clay, at 168 feet from the surface. A 14-inch pipe was then driven through the plastic clay, and into the gravel, sand, and stones beneath it. Within the 14-inch pipe, one of 7 inches in diameter, was driven through 42 feet of green sand, and 3 feet into the chalk, and the boring was continued to the total depth of 383 feet. The pipes were left standing some distance in the well, and most of the water came up the 7-inch pipe. The springs were stronger than those in the well in Orange Street.

The strata passed through were:—

	Feet.
Made earth	9
Gravel	5
Loam and gravel	7
Gravel	2
London clay	142
Plastic clay	30
Gravel, sand, and stones	11
Green sand	42
Chalk	135
Total depth	383

A tunnel, 6 feet in diameter, and about 400 feet in length, was driven to connect the two wells, the bottom of it being about 123 feet below Trinity high-water mark.

The engine house was erected, and a tank, in two compartments, was placed over it. The compartment which received the water directly from the springs, and which was intended to contain the low-service supply for the public offices, had an overflow, to take the excess of water into the other compartment which was intended to supply the fountains, through a pipe leading beneath Trafalgar Square, the pavement of which is about 17·83 feet above Trinity high-water mark. Another tank, intended for a high-service supply, was placed on the top of a tower, 15 feet square, carried up to the height of 54 feet. A catch well, 4 feet 6 inches in diameter, and 32 feet deep, was sunk immediately outside the engine house. A tunnel was driven from it beneath Castle Street and the National Gallery, containing the pipes for bringing back the water from the basins of the fountains, to the catch well.

A high-pressure condensing steam-engine, on the Cornish principle, having a cylinder 30 inches in diameter, with a length of stroke of 6 feet, was erected to work two pumps from the outer end of the beam; one of them was 11½ inches in diameter, with a length of stroke of 2 feet 6 inches, and capable of raising 100 gallons of water per minute, from the springs to the tank; the other pump was 18 inches in diameter, with a length of stroke of 5 feet, and capable of raising 550 gallons from the catch well into the tank, for condensation and for the supply of the fountains.

A high-pressure single-acting steam-engine, having a cylinder 30 inches in diameter, with a length of stroke of 5 feet, was erected to work a pump 10 inches in diameter, and with a length of stroke of 5 feet. This pump had, in addition to its bucket, a plunger, 6½ inches in diameter, working through its stuffing box, and by this means a delivery of water was effected, both with the up-stroke

and with the down-stroke. This engine was intended only as an auxiliary, when the principal machine needed repair.

The works were finished in December, 1844. The water rose to within 90 feet of the surface, or about 48 feet below Trinity high-water mark, and was found to be of good quality. The engine was first used on the 31st of December, 1844, and when pumping 110 gallons of water per minute, it could only lower the water in the well 4 feet. A list of the offices and places to which the water was supplied, is given in the Appendix : (page 28.)

In 1846, a further demand for water having been made, the $11\frac{1}{2}$-inch pump was removed, and one 18 inches in diameter, with a length of stroke of 2 feet 6 inches, was substituted, capable of raising 350 gallons of water per minute, from the springs. The Circular Basin, on Constitution Hill, was covered in at this time, and has since been used as a low-service reservoir. In December, 1847, Buckingham Palace was supplied from the works. In 1848, a pipe was continued from the main, near the Circular Basin, on Constitution Hill, to the Serpentine and to Knightsbridge Barracks; but some previously unknown defects in the old pipes, connected with the arrangement, interfered with the proper working, and the service was discontinued. This pipe was afterwards used for bringing water from the Serpentine, to the canal in St. James's Park. In 1849, a further extension of the works was made, by sinking a second well in the engine house, and the erection of a steam engine of 60 H.P., on Woolf's principle. This well was 6 feet 6 inches in diameter, to the depth of 100 feet; and, to give more space for the pumps, it was gradually enlarged to a diameter of 7 feet, and continued to the total depth of 176 feet; a tunnel being driven to connect it with the other wells.

A bore pipe, 15 inches in diameter, was driven through the plastic clay, within which it was intended to drive a smaller pipe, through the sand into the chalk, and then to continue the boring as in the other wells. In driving the large pipe a mishap occurred, which caused sand to come up the bore hole, and to mix with the water. The hole was stopped with bags of clay; and no further use has been made of it, than as a sump well to contain the pumps. The accident arose in this way: the well sinkers were instructed to leave the 18-inch pipe imbedded in the stratum of gravel, sand, and stones, which rests upon the green-coloured sand, keeping the top of the pipe standing up in the well, above the level at which the water would be stationary; then to drive the internal pipe through the sand into the chalk formation, as had been the previous practice at these works. In driving the pipe, great resistance was caused by the 'hugging' of the plastic clay, and considerable percussive force had to be used to force the pipes down; in consequence, several of the screws which held the joints

were shaken out. The Author considers, that the workmen drove the pipe too low, and that it passed through the layer of gravel, sand, and stones, into the sand beneath. Openings having thus been made for the escape of water through the screw holes, sand followed, in sufficient quantity to cause inconvenience. The only remedy which appeared certain, was to stop the pipe with bags of clay, and there was less hesitation in doing this, as it was found, that the other bore pipes gave sufficient water to keep the engine fully at work.

The steam engine has two cylinders, the larger being 35 inches in diameter, with a length of stroke of 6 feet; and the smaller one, 22 inches in diameter, with a length of stroke of 4 feet. It works one double-acting pump 13½ inches in diameter, with a length of stroke of 3 feet, for the supply to the fountains, and two 18-inch pumps, with a length of stroke of 20½ inches, for raising water from the springs into the tanks, above the building. At an average speed of sixteen strokes per minute, the fountain pump throws about 660 gallons, and the two spring pumps together, 600 gallons per minute.

In 1852, the tank tower was raised 20 feet, for the purpose of giving a better supply, at high service, to the upper tanks, in the river front of the Houses of Parliament.

The 60 H.P. engine is now principally used, and the supply of water from the springs is abundant. The pumping of 600 gallons per minute, equal to 432,000 gallons in twelve hours, lowers the water between 20 feet and 24 feet; it then remains stationary, as long as the engine is kept working. The height to which the water will stand when at a state of rest, varies in wet and dry seasons; but the head does not appear to be gradually lowering. When the works were first put in operation, in 1844, the water rose to within 48 feet of Trinity high-water mark, in the well in front of the National Gallery. From observations extending over a considerable time, it has been ascertained, that in July and August, 1845, it stood within 43 feet of Trinity high-water mark, and afterwards, as follows:—

Years.	Least Depth below T. H. W. M.	Greatest Depth below T. H. W. M.
1846 . . .	43 feet.	57 feet.
1847 . . .	43 "	66½ "
1848 . . .	60 "	63 "
1849 . . .	51 "	62 "
1850 . . .	52 "	62 "
1851 . . .	56 "	64 "
1852 . . .	56 "	63 "
1853 . . .	55 "	63 "
1854 . . .	55 "	65 "
1855 . . .	56 "	64 "
1856 . . .	53 "	73 "

and on the 1st of December, 1858, it stood at 66 feet, being about the same level as in 1847.

There is no doubt, that in these wells, the greatest portion of the water is obtained from the chalk. This is confirmed by two facts; first, that when boring into the chalk beneath the well in front of the National Gallery, the auger, or boring tool, dropped suddenly several feet, clearly indicating, that a fissure was struck; and secondly, that when any repairs are needed at the bottom of the pump work, it has frequently been the practice to plug the 7-inch pipes which are driven into the chalk, and thus to stop the water from rising in them, when an engine soon empties the wells. That large quantities of water do exist, and are stored in the chalk, is proved by the supplies afforded from that source, to the towns of Brighton, Croydon, Deal, Epsom, Ramsgate, and Woolwich.

The uncertainty, however, of obtaining a good supply in the chalk is forcibly shown, by the facts connected with the well sunk on the premises of Messrs. Truman, Hanbury, and Co., some particulars of which were given in a Paper by Mr. Davison, read before the Institution in the year 1842.[1] In the autumn of 1856, the Author was consulted by that firm, as to the means of obtaining a greater supply of water. He recommended, that the original plan, as described by Mr. Davison, should be carried out; this was to continue cylinders through the sand, to that depth which showed the greatest indication of water, and to set them fast in the chalk; then to tunnel on both sides of the well, continuing the process until a sufficient quantity of water was obtained. The bore hole had been deepened, in 1850, from 400 feet to 530 feet, and the chalk, at that depth, being perfectly dry, it was useless to bore deeper. This recommendation having been adopted, the works were commenced in 1857. The pump work was removed, and a length of 110 feet of cylinders, 7 feet in diameter, was placed within the fixed cylinders, and driven firmly into the chalk, the sand and water above the chalk being completely shut out. The water in the cylinders had stood within 98 feet of the top, or about 63 feet below Trinity high-water mark. The removal of the concrete from the bottom of the well, by the aid of the chisel and the miser, in 90 feet of water, was a very laborious and expensive operation, particularly as the concrete was found to be composed of granite stones, furnace bars, cement, etc., all of which had to be broken by the chisel. The well was then dug to the depth of 300 feet from the top, being discontinued at that depth, as no water came up the bore hole. At the depth of 285 feet, the chalk showed indications of water, and the floor of the tunnels was com-

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. ii., 1842, p. 192.

menced. These tunnels, 5 feet 6 inches high and 4 feet wide, were driven north and south; that on the north side to the length of 57 feet, and that on the south side to 48 feet. The quantity of water now obtained, does not exceed $12\frac{1}{2}$ gallons per minute, equal to 18,000 gallons in twenty-four hours.

The cost of the works in the well was . .	£1,900
,, of the pumps	450
Total	£2,350

The water of the springs in the sand has been taken by tapping the cylinders, and the water now flows free from sand. It is evident, that the water from the sand springs may be safely taken, without disturbing the sand, merely by drawing the supply from the bottom instead of, as hitherto, from near the top of the sand.

A well was sunk at Messrs. Combe and Delafield's brewery, under Mr. Easton's direction, to the depth of about 48 feet into the chalk; no tunnels were driven, and the quantity obtained from that source was 70 gallons per minute. The water stands 26 feet higher in this well than in the Trafalgar Square well, when the water in both wells is in a state of rest.

[APPENDIX.

APPENDIX.

	£.	s.	d.
The Cost of the Works, as completed in 1844, was	8,392	18	8
The Working Expenses per annum, as per contract, were	492	10	0

The Places supplied, and the Revenue derivable therefrom, at the rates previously paid for Water, were :—

	£.	s.	d.
For Watering the Streets, &c., including Whitehall, Parliament Street, the two Palace Yards, Carlton Terrace, Cockspur Street, Charing Cross, Parliament Square, the Sessions House, Westminster	245	18	0
St. George's Barracks, Castle Street	100	0	0
National Gallery	10	0	0
Royal Academy	10	0	0
Office of Woods	10	0	0
Gwydyr House	15	0	0
Admiralty	42	10	0
Foreign and Colonial Offices, and the Chancellor of the Exchequer's House and Office, Downing Street	76	15	0
Treasury	50	0	0
Pay Office, Civil Service	8	8	0
Home Office	20	10	0
Board of Trade	20	0	0
Council Office	24	0	0
Whitehall Chapel	1	12	0
Exchequer Office and Mr. Phipps' House, Middle Scotland Yard	8	8	0
Exchequer Seal and other Offices	5	2	0
Two Official Houses in Spring Gardens	6	14	0
No. 5, Whitehall Place	3	3	0
Horse Guards, War Office Department, Whitehall Yard	46	8	0
New Houses of Parliament	200	0	0
	£904	8	0

Nothing is charged in the above list for the water supplied to the fountains, nor for the following places which were added and supplied :—

State Paper Office.
Mr. Phillips's House.
India Board.
Parliamentary Offices, Abingdon Street.
Sir George Rose's House.
Mr. Currey's House.
Museum of Economic Geology.
Conduit in Middle Scotland Yard.

The Places supplied and the present Revenue, are:—

	£.	s.	d.
St. George's Barracks, Castle Street	100	0	0
National Gallery	10	0	0
Royal Academy	10	0	0
Office of Woods	10	0	0
Gwydyr House	15	0	0
Admiralty	42	10	0
Foreign and Colonial Offices, and Chancellor of the Exchequer's House and Office, Downing Street	76	15	0
Treasury	50	0	0
Pay Office, Civil Service	8	8	0
Home Office	20	10	0
Board of Trade	20	0	0
Council Office	24	0	0
Whitehall Chapel	1	12	0
Exchequer Office and Mr. Phipps' House, Middle Scotland Yard	8	8	0
Exchequer Seal and other Offices	5	2	0
Two Official Houses in Spring Gardens	6	14	0
No. 5, Whitehall Place	3	3	0
Horse Guards, War Office Department, Whitehall Yard	46	8	0
New Houses of Parliament, supply of Water equal to 250,000 gallons per day, during the meeting of Parliament, at 3*d.* per 1,000 gallons, 130 days	406	5	0
Ditto, 235 days at 60,000 gallons per day	176	5	0
State Paper Office	4	4	0
Mr. Phillips's House	4	0	0
India Board	20	0	0
Parliamentary Offices, Abingdon Street; Sir George Rose's House; Mr. Currey's House	15	0	0
Museum of Economic Geology	5	0	0
Conduit in Middle Scotland Yard	20	0	0
Buckingham Palace and Swiss Cottage	73	0	0
Buckingham Gardens	137	7	4
Royal Mews	120	0	0
St. James's Palace	164	4	0
Marlborough House	36	0	0
Ordnance Office, Pall Mall	30	0	0
Mews, late the Queen Dowager's	31	10	0
Wellington Barracks and Queen's Guard Room, Buckingham Palace	105	0	0
St. Martin's Baths and Washhouses	180	0	0
St. Martin's Roads	82	12	6
Penitentiary	120	0	0
Supply to the Fountains, 500 gallons of water per minute, equal to 300,000 gallons per day, at 1½*d.* per 1,000 gallons, or per year	684	7	6
Watering the Inclosures in St. James's Park	20	0	0
	£2,893	5	4

[Mr. Amos

Mr. Amos repeated the statement contained in the Paper, that the water in the wells had not diminished; during a very dry season, it was gradually lowered, but in wet weather, it rose again to its original level. At the present time there was plenty of water, the principal portion of which, in his opinion, came from the chalk, into the well on the left-hand side of the front of the National Gallery. In other instances, the same success might not have followed from operations in the chalk; for the railway cuttings had shown, that whilst the chalk formation was, sometimes, extremely friable, it was, at other times, so hard, as effectually to prevent the infiltration of water. The sinking of the wells called for no particular remark, the results being such as were ordinarily met with in practice. The miners' dial was found to be useless, owing to the iron in the London clay affecting the magnet.

In answer to a question from the Reverend Mr. Clutterbuck, as to the period of the year in which the level of the water had been ascertained, in 1847 and 1858, at which times, it was stated to have been the same,—Mr. Amos said, that the level was taken in each case, at precisely the same period, in December of each year.

The Reverend J. C. Clutterbuck said, he had devoted considerable attention to the subject, and had, some years ago presented to the Institution several Papers,[1] which had contributed, he had been assured, to its elucidation. The main point sought to be established in the Paper under discussion, appeared to be, that an abundant and reliable supply of water could be obtained from the wells in Trafalgar Square. Instances, however, had been quoted, amongst others, that of Messrs. Truman Hanbury, and Co., in which the results were very different; and he had been told by Mr. Barclay, that in his establishment, they had been obliged to renounce all dependence upon water from the chalk, and could only rely upon the water companies for a regular supply. That being the case, he presumed it would be admitted as a general proposition, that a considerable amount of money had been uselessly spent by various establishments, in trying to procure a large permanent supply of water, from the sand and chalk underneath London. In all his publications upon the subject, from 184[illegible] up to the present time, he had given repeated cautions, not to rely upon being able to pump a large supply of water from the chalk for either sufficient water would not be obtained, or mischief would ensue in other quarters. So long ago as the year 1840, in speaking of the deep wells in London, he said:—"that the exhaustion of water from these wells lessens, or destroys the supply to others near them, is well known, in spite of the mystery thrown over th[e]

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. ii., 1842, p. 155; 1843, p. 15[illegible] and vol. ix., p. 151.

subject. The aggregate of these causes must produce some general effect. It has even been suggested, that a connection may be traced between the known, and otherwise unaccountable, defalcation of water in the River Colne, and others, on every Monday, and the probable periodical depression and replenishment of the water level under London; a solution of this obscure problem which is not absolutely impossible. This subject is beset with no ordinary difficulties, arising chiefly from the geological condition of the centre of the basin, where the continuity of the water level, as it exists in the chalk, is interrupted by the superincumbent London and plastic clays: a portion of the difficulty would, however, be removed, if the relative freedom of passage to the water, by the chalk and sand beds of the plastic clay formation, were correctly ascertained, which, as a part of the whole question, is open to practical and scientific investigation, well worth the time which those who have opportunity, may be inclined to bestow upon it."[1]

He had never seen any reason to depart from that statement. It was certain, that from an aggregate of causes, a general depression of the water level under London had been produced. This opinion was confirmed by the statement in the Paper, that the level of the water in the wells was, originally, 48 feet below Trinity high-water mark, and that it stood now at 66 feet below that level. In endeavouring to ascertain the sources of that water, he had been irresistibly led to the conclusion, that there was an infiltration from the river; because he found, that the depression under London was extending more rapidly towards the north of the river, than at the centre of the greatest abstraction by pumping, and he believed it would also be found, that the depressed level rose towards the tidal outfall. In his Paper of 1850, he had particularly alluded to these facts as worthy of notice, and important subjects for future investigation. He there observed:[2]—"It has been before stated, that the natural vent, or outfall, of the chalk waters under London, is the mean tide-level in the River Thames, below London Bridge; and that the normal, or natural condition of the water level, has been entirely altered, there being a permanent depression, varying from 50 feet to 60 feet, at the lowest point.[3] As the level in each well is lowered, by pumping, a vacuum, at a still lower level, is formed, by which the drainage from above is accelerated, and by which the waters of the Thames, passing over the outcrop of the sands of the plastic clay and chalk,

[1] *Vide* "A Letter to Sir John Sebright, Bart.," by James C. Clutterbuck, M.A. Tract. 8vo. (pp. 78). Watford, 1841. Page 14.

[2] *Vide* Minutes of Proceedings Inst. C.E., vol. ix., p. 154.

[3] "It has been reported, that at Messrs. Reid's well, after a cessation of pumping for twenty-four hours, the water in the large subterranean reservoir, excavated in the chalk, does not rise to within 100 feet of Trinity high-water mark."

will naturally descend through those strata, and thus the natural outfall is converted into a source of supply, and the drainage is reversed. This supposed influx of the tidal waters, which, from the geological condition of the basin, at the point in question, must take place, would be easily proved; first, by having a correct series of geological observations made when sinking wells; secondly, by ascertaining to what extent, alternations of level in wells, within certain limits, are coincident with the tide; and, thirdly, by a strict and close chemical examination of the nature of the waters, to ascertain whether those ingredients with which tidal waters are usually charged, are there present. As facts are collected and published, it will be shown, that a copious infiltration of water from the bed of the River Thames does actually take place; indeed, this source of supply never fails, varying only with the height and strength of the tides. It is certain, that this must, in a great measure, counteract the drainage from other quarters; but what the ultimate effect will be upon the other sources of supply, is a problem to be solved by time."

That was the conclusion at which he had then arrived, from his own observation; and the sections since published by Mr. R. W. Mylne, in which was given the outcrop of the sand and chalk, confirmed that statement. If the reasoning based on these facts was correct, it followed, necessarily, that filtered Thames water was being pumped from these wells. In a Paper by Mr. Frederick Braithwaite, (M. Inst. C.E.,) read before the Institution in May 1855, it was shown, by the analyses of different waters,[1] especially that obtained from the wells at Trafalgar Square,[2] that there was a larger quantity of saline matter than was ordinarily found in chalk water, and which could not be accounted for by the solution of salt, in the strata through which the water passed, or in which it was found. He did not wish to detract from the quality of the water, but it was a positive fact, that it contained 25·7 grains of sea salt per gallon. He knew, that tidal water had found its way into wells, at other places where they had been sunk below the level of the tidal outfall; such had been the case at Ramsgate, at Portsmouth, and, more particularly, at Liverpool, where the wells invariably drew in the salt water, if sunk below a certain level. At Portsmouth, there was great danger of the dockyard and of the town itself being, at some future day, deprived of water. He had been asked to give his opinion upon the state of the wells at Haslar Hospital, and he soon found, that one of them was impregnated with salt. After carefully examining the water in the surface gravel, into which some of the wells of the hospital were sunk,

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xiv., p. 509.
[2] *Vide* ibid., p. 520.

he ascertained, that the salt water came through a bed of sand beneath the subjacent clay, into which the tidal water found its way, from an artificial, and not from a natural, cause; this evil had now been remedied by shutting out the tidal water, and sinking the bore pipe into a lower stratum of sand. Many of the wells in Portsmouth were tidal, showing that the water by which they were supplied, had its outfall in the sea; if, therefore, those wells should, at any time, be drawn upon to a great extent, he believed, that the tidal water would infiltrate into them. The Government should be cautious how they treated those wells. He had heard, that a private company had been allowed to acquire a source of water, of which the Government had thus permitted themselves to be deprived, although it was, probably, the only source whence could be procured a supply of pure water for the town. It was a difficult geological problem, whence the water in the deep wells at Portsmouth was derived, and how so much water found its way into the sand beds above the plastic clay, where it was collected at different levels. There was another instance in point, close to the Institution; the water from the Thames supplied, to a certain extent, the works in St. James's Park. It had been stated, that more water could be raised there at high water than at low water; though it came superficially, differing in that point from the deeper wells, still it came in to replace a depression below the tidal outfall. The special attention of Engineers should be directed towards watching the quality, as well as the quantity, of the water, and the level at which it stood in the wells.

Mr. FREDERICK BRAITHWAITE said, that in 1846,[1] the subject having been again referred to in 1850,[2] and in 1856,[3] he had exhibited and described a chart, showing the situations of the deep wells of the Metropolis, and he had brought under notice an Artesian-well system, then projected for supplying London with water, to the extent of 140,000,000 gallons per day, by sinking eighty wells on the north side, and forty wells on the south side. He stated at the time, from his own experience upon the subject, as well as that of his Father and his Brother, that such a scheme could not possibly succeed. Numerous letters and pamphlets were published to show, that he was in error, and that by sinking 300 feet, or 400 feet, any requisite supply of water could be obtained; Providence having, of course, placed it there, in anticipation of the existence of London on the ground above. The project, however, was ultimately abandoned.

Mr. Braithwaite now exhibited two diagrams; the first, showing the monthly rainfall and the percolation through Dickinson's rain

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. v., p. 478.
[2] *Ibid.*, vol. ix., p. 165.
[3] *Ibid.*, vol. xiv., 512.

gauge, from 1838 to 1858, also the daily rainfall for 1856; the second, showing the average monthly decrease of the water at Messrs. Combe and Co.'s well, taken daily from 1837 to 1857, when the well became dry, as he had predicted the year before. He then referred to two wells upon the premises of Messrs. Combe and Co., both of which were originally sunk to within 40 feet of the chalk; but in one of them very deep borings had been, subsequently, made into the chalk, yet only a few gallons of water per minute were obtained. More water being required, it had been stated, that by sinking a well on the backbone of the chalk, an "inexhaustible supply could be obtained." Had that assertion been correct, it would only have been necessary to sink the iron cylinders in the first well into the chalk. But a new well being deemed desirable by the then advisers of the firm, cylinders were driven through the sand strata into the chalk, shutting out the sand springs; deep borings were carried into the chalk, as had been already done in one of the wells above alluded to, and with the same result; very little water being obtained. It was only by boring holes into the sand strata, that a supply of 70 gallons per minute could be procured, but this quantity was not derived from the chalk.

Mr. Braithwaite next referred to the well in Covent Garden, from which, the pumps being 15 feet, or 20 feet above the level of those of Messrs. Combe and Co., no water could be obtained after the early morning. Here again, an inexhaustible supply was promised from the chalk, into which it was proposed to drive a pipe, 12 inches in diameter; but this pipe failing, one, 3 inches in diameter, was substituted. As in the last case, no water was obtainable from the chalk, and the pumps were, eventually, lowered, as advised by him in the first instance.

It had been argued, that if there was an average rainfall of 30 inches per annum, 10 inches would flow into the river, 10 inches would be evaporated, or be absorbed by the land, and the remaining 10 inches would percolate into the deep springs under London. He contended that, in that estimate, a sufficient allowance had not been made for evaporation. If the quantity of water in the London basin was annually replenished by 10 inches of rainfall, how was it possible, that by the abstraction of a few million gallons daily, so serious a depression should have taken place as that shown from actual daily gaugings, extending over the last thirty-two years? He did not attach too high an importance to rain gauges, as bearing upon this question, for much depended upon the absorbent nature of the soil, which varied greatly in different localities. It would appear, that at certain periods, a large quantity of rain fell in Hertfordshire, whilst there was little, or no percolation; the evaporation, consequently, had been very nearly

equal to the rainfall. It must be apparent, that the necessity for an additional supply of water in any locality, must arise from the excess of evaporation, or waste, over the rainfall. The supply of water necessary for the Serpentine, and for the ornamental water in St. James's Park, must be regulated by that excess. Mr. Glaisher had come to the conclusion, that from any surface of water exposed to the rays of the sun and the action of wind, the evaporation would be equal to 30 inches per annum. The average rainfall, had been, of late years, only 24 inches; consequently, the requisite additional supply would be only 6 inches. If, as had been publicly stated, it was found necessary to pump 500,000 gallons per day into the ornamental water in St. James's Park, which, upon an area of 40 acres, would be 1 inch per day, and 1,000,000 gallons per day into the Serpentine, which upon an area of 80 acres, would also be 1 inch per day, that supply would amount, for three hundred days, to 25 feet per annum, whilst the loss by evaporation was only 6 inches per annum. It was clear, that any amount of pumping in excess of 6 inches, must be required to meet a deficiency, arising from some other cause than the waste by evaporation. What, then, became of this enormous quantity of water? It could not evaporate; it did not overflow; it must, therefore, pass by filtration into other channels, as had been stated by competent authorities; so that, if the quantities alleged were correct, an endless chain of water was being pumped over and over again, to no useful purpose. The extent of under-drainage, and the present improved system of tillage which brought the land, mechanically, into a state fit for the absorption of water, would sufficiently account for a large amount of rainfall not reaching the springs, so as to afford that inexhaustible supply of water, which had been calculated upon from those sources.

Mr. Homersham had gathered from the Paper, this important fact, that, in December, 1858, after yielding daily, during eleven years, a very considerable and increasing quantity of water, the Trafalgar Square wells remained at the same level as in December, 1847. If, therefore, in the wells upon the premises of Messrs. Combe and Co., there had been, during these eleven years, a gradual depression of the level of the water, it could not have arisen from any deficiency in the London basin. The present Paper furnished a refutation of the title of the one read before the Institution, in 1850, "On the periodical alternation and progressive permanent depression of the chalk-water level under London,"[1] and also of the argument by which it was attempted to be supported. It was evident, that in the Trafalgar Square wells, that depression had not taken place, and his own experience con-

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. ix., p. 151.

firmed the fact, that when wells were properly made and sunk, in suitable localities, into the chalk, the water would stand, during a series of years, at the original level. To account for the permanence of the water level in the Trafalgar Square wells, it was asserted, that there was an increasing quantity of salt in the water, which led to the inference, that the source of supply was the Thames. This was a chemical question, and upon the authority of Mr. Dugald Campbell, who analysed the water in 1847, and again in 1857, he asserted, that instead of the saline matter having increased, it had actually diminished. Speculative opinions were thus met by two facts: first, that the level of the water in the Trafalgar Square wells was not permanently lowered; and secondly, that it contained less saline matter now, than formerly.

The impossibility of obtaining a large supply of water from the chalk had been repeatedly urged; but an appeal to facts controverted this statement also. In 1853, a company was formed to supply Charlton, Plumstead, and Woolwich, with water from the chalk. The wells and principal works were executed under his direction, and a supply of 600,000 gallons per day was the result. The works were opened in 1854, and in 1857, the quantity of water required, owing to the rapid increase in the number of consumers, became so large, that a new bore hole, 18 inches in diameter, was carried down from the bottom of the well, to a further depth of 500 feet, and the supply was thereby increased to more than 1,000,000 gallons per day; yet the water in the well now stood at the same level as at first. The Kent Water Company who, up to 1854, had obtained their whole supply from the River Ravensbourne, which had become deteriorated by sewage, finding that the consumers preferred the pure soft chalk-water of the Plumstead Company, had followed their example, and had sunk a well, from which they obtained a supply of 1,250,000 gallons per day. It was an important fact, that the sinking of that well had not produced any effect whatever upon the supply of the Plumstead works. Pleased with their success, the Kent Company proceeded to sink another well, not 500 yards distant from the first, which yielded an additional quantity of more than 1,500,000 gallons per day, and they had thus obtained from the two wells during the last two, or three years, nearly 3,000,000 gallons per day; yet the level of the water remained the same as when the wells were first used. The same company had either sunk, or were now sinking, a third well. Thus, in consequence of competition, a large suburban district of the Metropolis was now supplied with water from the chalk, and that water was practically free from chloride of sodium, containing no more salt per gallon, than the Thames water above Teddington Lock. He would not, at present, discuss the complicated question

of the amount of evaporation, but would simply record his dissent from the opinions which had been expressed upon the subject.

Mr. FREDERICK BRAITHWAITE observed, that the analysis made by Dr. Clark showed, that the water from wells on the north side of the Thames, contained 79·9 grains of sea salt per gallon, and little, or no carbonate of lime. It was important also to bear in mind, that the Plumstead well water was procured from the chalk, whilst the water in the wells of Trafalgar Square was chiefly derived from the sand, and it, undoubtedly, contained a large proportion of salt. The London basin did not extend so far as Plumstead; no fair comparison could, therefore, be instituted between the wells at that place and those under London.

The Rev. Mr. CLUTTERBUCK remarked, that his Paper which had referred to, having been written in 1850, could not be made answerable for what had since occurred. Up to that time there had been, undoubtedly, a depression in the level of the water; and from the diagram presented by Mr. Braithwaite, it appeared, that it had continued up to the present day. With regard to the analyses of water, he suggested, that it would have been more satisfactory, if the samples taken at different periods, had been analysed by the same person; and it was also very important to know from what spot they were taken. The water in the basins at Trafalgar Square would, probably, be found to contain a greater quantity of salts than the water in the well, because, in passing several times through the fountains, it would be subjected to evaporation, whereby the bulk of the water would be decreased, whilst all the saline particles would remain.

Mr. HEMANS mentioned, with a view of obtaining some explanation of it, a singular circumstance that had fallen under his own observation. Having occasion to sink a well for railway purposes, in a large district of cavernous limestone, in the west of Ireland, a shaft, 9 feet in diameter, was carried down about 50 feet, or 60 feet, when a supply of water was obtained, but not in sufficient quantity. An auger, 3 inches in diameter, was then introduced to the further depth of 30 feet, when, to the surprise of all, instead of obtaining more water, that which had been previously secured, entirely disappeared. He could only account for the sudden disappearance of the water, on the supposition, that some channel had been opened, connected with the sea, although it was at a distance of thirteen miles. The bottom of the auger hole was just above the level of the sea, but it was far below that of the adjacent rivers. The phenomena of the district were altogether extraordinary: the rivers disappeared for a distance of three miles, or four miles, when they re-appeared upon the surface.

Professor TENNANT offered some remarks upon the supply of water in London. The population was increasing at the rate of

fifty thousand per annum, whilst the water supply, on the contrary, had considerably diminished. Thirteen years ago, in most of the leading thoroughfares, a good supply was obtained from wells sunk into the gravel; there were several in the Strand, but they were now closed, in consequence of the quantity of gas which had penetrated through the soil, rendering the water no longer available for the inhabitants of the locality. It was a very important question, how this water was to be obtained. The supply from the chalk was not constant; there were several means of verifying the fact, and it might be variously accounted for. The supply from the rainfall was, to a great extent, carried off by the sewers, and the loss arising from that cause, was continually increased by the expansion of the town. Another cause, which operated upon a large scale, was the construction of the intercepting sewers, which not only drained the water from the wells in their direction, but also the water both from the gravel and from the sand below it.

Mr. Peter Bruff proposed to call the attention of the Meeting to a deep boring, recently made at Harwich, for the purpose of obtaining fresh water, which had been attended with some extraordinary results; but before giving a detailed account of this failure, for such it had been, he would notice another boring that he had made in the same locality, which presented different features. The town of Colchester, in Essex, containing about twenty thousand inhabitants, had been, since the year 1808, supplied by a company, with water from the land springs overlying the London clay in that neighbourhood. In 1850, in consequence of the springs having, to a great extent, run out, and become contaminated, it was found imperatively necessary to seek for a more efficient supply. The company having, through legal and other difficulties, failed in obtaining a surface supply, he advised, that a trial boring should be made into the chalk, which was carried down to a depth of about 340 feet from the surface, but with no satisfactory result. As it was found necessary to insert pipes for the entire depth, and they could not be forced down of a uniform size throughout, he was compelled to introduce smaller pipes, until the bore, at the depth stated, became useless. Another well, 9 feet in diameter, was subsequently sunk to a depth of 40 feet, and he then bored till the depth from the surface was 353 feet, when a fissure in the chalk was reached, from which was extracted a quantity of fine broken flint, and an abundant supply of excellent water suddenly burst forth, which had sufficed for the wants of the town from the year 1851 to the present time, and no diminution in the yield appeared to have taken place. The strata passed through were:—

Soil	6 feet.
Gravel	4 „
London clay . . .	70 „
Mottled clay . . .	20 „
Green sand	3 „
Dark plastic clay . . .	40 „
Chalk with flints . . .	210 „
Total . . .	353 feet.

The bore hole was protected throughout its whole depth, by wrought-iron pipes, 8 inches in diameter, and perforated at the bottom to the height of 20 feet. The water now stood at about 5 feet above high-water mark, the same level as nine years ago. The wants of a town like Colchester were not large, averaging about 1,250,000 gallons per week; but the supply might, if necessary, be very much increased.

He would now refer to the boring of Harwich, which town was situated immediately upon the sea coast, about eighteen miles east of Colchester. The great importance of obtaining an adequate supply of fresh water, not only for the inhabitants, who had almost entirely to depend upon the rainfall, but also for the shipping which frequented the capacious harbour, would be inferred from the fact, that during the great French war, the North Sea fleet was largely dependent upon Harwich for supplies, especially of fresh water, which had to be brought from long distances in boats, as none could be obtained in the town. Even during the late Russian war, when a few gunboats put into the harbour, water had to be sent by railway to supply their wants. Many attempts had, in consequence, been made, both by the Government and others, to obtain an adequate supply of fresh water. The earliest authentic account was that of a boring made by some private individuals in 1820, when a very small quantity was obtained from the strata above the chalk, which was entered at a depth of 64 feet from the surface. The boring was then continued to a depth of about 400 feet, but as the salt water rose in the bore hole, after sinking some distance further in the chalk, the attempt was abandoned. Several other local efforts to obtain fresh water had been subsequently made; but after an investigation of the circumstances, he came to the conclusion, that in none of the cases, had the parties gone to the expense of jointing their pipes, with sufficient accuracy. He determined, therefore, to use cast-iron pipes, with water-tight joints, and to sink them sufficiently deep into the chalk to shut out the salt water, and thus to reach those capacious springs which had been ascertained to exist, at no very great

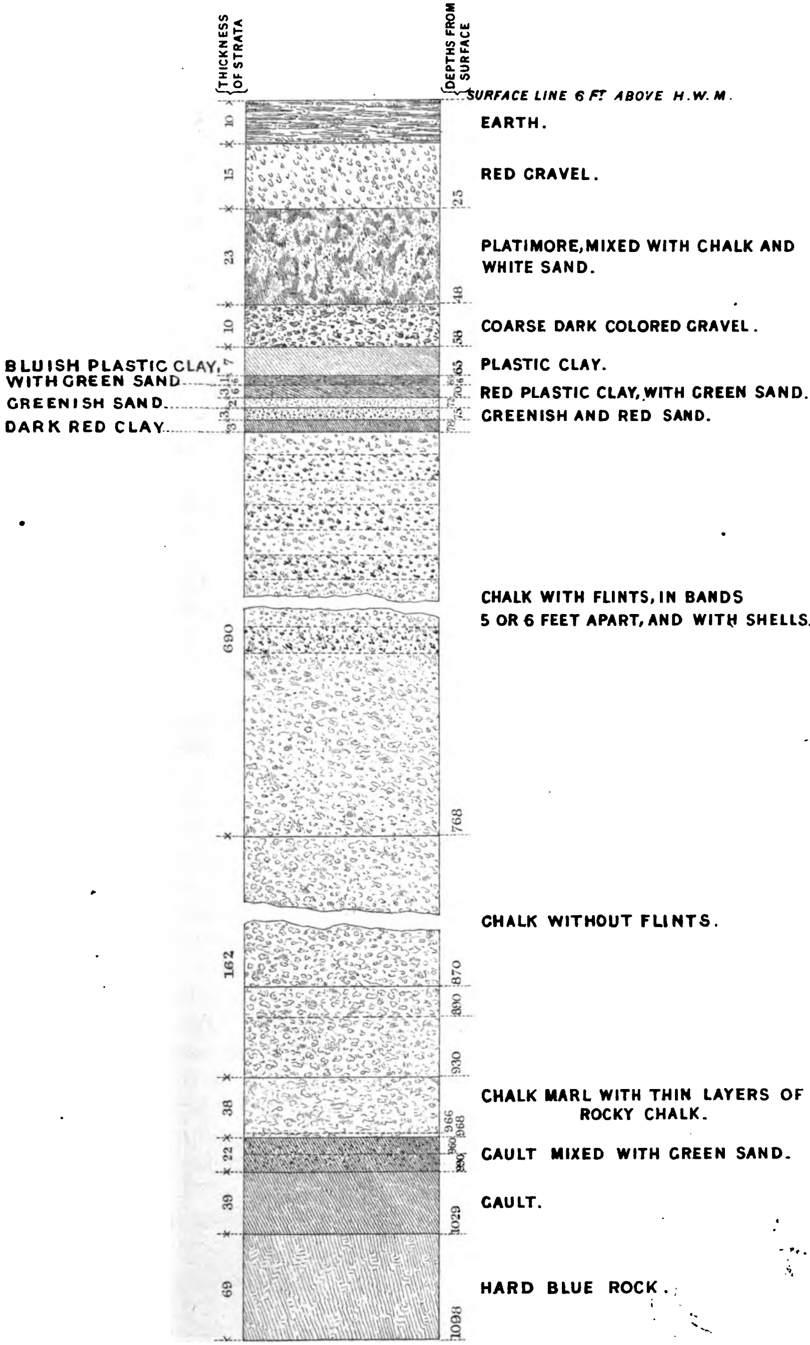
distance, in the chalk. His first operation was to sink a shallow well, on what had formerly been the foreshore of the harbour; from the bottom of the well, cast-iron pipes, 10 inches in diameter, in lengths of 9 feet, with water-tight joints, were forced down 50 feet into the chalk, a depth, he supposed, sufficient to prevent the salt water from descending into the bore hole; but with no other result than salt water, of precisely the same character as in the harbour and sea immediately adjacent. The pipes were then forced down to a depth of 480 feet, and the boring was continued, passing through numerous bands of flint in the upper stratum of chalk, one of which was of considerable thickness, but without any fresh-water springs being, apparently, tapped, as the bore hole remained filled with salt water. He finally resorted to the expedient of pumping, by which the surface of the water was lowered 3½ feet in twelve hours, by the extraction of about 200,000 gallons; but on ceasing to pump, it again rose 7 inches in five minutes, 2 feet in three hours, and it recovered its original level in less than eight hours, without any apparent difference in the character of the water. On further consideration, he thought he would endeavour to pass through the chalk, and so, possibly, obtain water from the upper green sand. He proceeded with the work down to that stratum, which was fairly denoted, but so mixed with marl and gault, as scarcely to be permeable; and he was again disappointed. He then determined to penetrate through the gault, hoping to obtain an abundant supply from the lower green sand, the equivalent stratum to that which supplied the Artesian well at Grenelle, in the Paris basin; but a few grains of coloured sand mixed with gault, were the only indication of the existence of that formation. He next thought of attempting to reach the Wealden clay formation, but whilst deliberating whether to proceed, or abandon the work, an extremely hard rocky stratum was struck upon, somewhat resembling slate, having a line of cleavage with bed joints dipping considerably, and apparently, containing no fossils; for which neither he, nor the most eminent geologists who had been consulted, could account. The different strata passed through were shown in Plate 1A. Having called attention to specimens of the rock to which he had referred, Mr. Bruff remarked, that the boring remained in that state to the present time. The water ebbed and flowed in the pipe with the tide, but not to the same extent as in the adjacent harbour: the difference in the oscillation was considerable, although high and low water were marked nearly at the same times.

In a Paper upon this boring, read before the Geological Society, on the 16th of December, 1857,[1] Mr. Joseph Prestwich observed,

[1] *Vide* "The Quarterly Journal of the Geological Society of London," vol. xiv., page 249.

ARTESIAN BORE AT HARWICH.

PL. 1A VOL. XIX.



"that this result had, necessarily, an important bearing on the evidence furnished by the Kentish Town well,[1] and, combined with the fact of coal rocks having been found by the deep boring at Calais, it tended to prove Mr. Godwin Austen's view of the existence of a westward extension of a ridge of the crystalline and palæozoic rocks of the Franco-Belgian area, beneath portions of the cretaceous deposits of the south-east of England." The failure in obtaining fresh water by boring through the chalk at Calais, a few years since, of which an account was to be found in Mr. Prestwich's work on "Water-bearing Strata,"[2] and the failure at the Kentish Town well, referred to in the extract just given, appearing to be somewhat analogous to that at Harwich, it would, in Mr. Bruff's opinion, be useful and interesting, if the strata of the whole were grouped. The apparent impossibility of obtaining fresh water from the chalk formation at Harwich, though it was found in abundance at Colchester, and also at Ipswich, twelve miles north of Harwich, would denote the existence of some local fault within that short distance. He might add, that a similar unsuccessful attempt had been made by the late Mr. Warner, the bell-founder, to obtain water upon his estate at Walton-on-the-Naze, on the same coast, and about six miles from Harwich. In that case, also, it was found impossible to get rid of the salt water.

He did not know the total sum which had been expended at Harwich, but the wages alone amounted to £2,054. 15*s.*, exclusive of tools, pipes, and superintendence. The cost of the last 70 feet of the boring into the hard rock, was at the rate of £13. 5*s.* 8*d.* per foot. The surface of the ground at the well, was 6 feet above high water, and the top of the chalk was 74 feet below it. At Colchester, the level of the top of the chalk was 121 feet below high-water mark.

As interesting for comparison and reference, he gave a list of the strata passed through, in boring for water for some large tannery works, made about the year 1855, at Combs, near Stowmarket, as furnished to him by the proprietor, Mr. Webb, who obtained an abundant supply of water, which was believed to come from the upper green sand. Mr. Bruff had no means of accurately stating the level of the surface above high water, but he judged it to be about 70 feet.

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1 *Vide* "The Quarterly Journal of the Geological Society of London," vol. xii., page 6.

2 *Vide* "A Geological Inquiry respecting the Water-bearing Strata of the Country around London, &c." By Joseph Prestwich, Jun., F.G.S. 8vo. London. 1851. Page 208.

Clay to the sand and first springs . . .	30 feet
Sand to the chalk, (very solid)	27 „
Chalk with flints	504 „
Chalk without flints	240 „
Chalk with marl	73 „
Upper green sand	10 „
Gault	11 „
Total from the surface . . .	895 feet.

Mr. Bazalgette said, that assuming the correctness of the statement, that the rainfall was disposed of in three equal portions, it was evident, that the portion which passed off by evaporation was not available at all; that the greater portion of that which passed into the rivers was, at the time of heavy rains, or within a short period afterwards, carried to the sea, under the name of flood waters, leaving comparatively little available for water supply; and that thus, the main source whence it could be obtained, was the portion absorbed into the earth. The companies which supplied London derived, therefore, the bulk of their water from that portion of the rainfall which, after being absorbed by porous strata, had penetrated through its fissures down to the valleys, to rise again in springs, and to supply fresh water to the Thames. It appeared to be admitted, that it was objectionable to derive the supply of water for the Metropolis from the Thames, and that, if practicable, some other source should be resorted to. The large existing demands upon the waters of the Thames had, during dry seasons, tended to injure the navigation by reducing the scour; and of late years, the abstraction had greatly increased, as appeared from the returns of the water companies. The river, consequently, had become unwholesome and offensive; indeed, the sanitary condition of the Thames might be determined with certainty, by gauging the quantity of water flowing over Teddington Lock, and taking into account the then state of the thermometer. It, therefore, became of importance to ascertain, whether a sufficient supply of water for the Metropolis, could not be derived from that portion of the rainfall which was absorbed into the chalk, and did not reflow into the Thames, without reducing the quantity of fresh water flowing down the river, or producing injury in other respects. So many conflicting opinions had been given with regard to the permanency of that supply, and it varied so materially in different portions of the London basin, that it became important to inquire into the character of the chalk at those places, and the whole of the conditions under which the supply was found to exist, or had failed. Such

information would be very valuable, and would, probably, afford data, from which to judge of the presence, or absence of water, before sinking. The 8 inches, or 9 inches, of rainfall per annum, which was absorbed into the vast chalk basin surrounding London, still remained to be accounted for, and a bare statement of facts, that certain wells were depressed whilst others remained at their original level, was an insufficient basis on which to found an argument, that an important source of water supply might not be derived from the chalk formation, or that the present injurious demand upon the waters of the Thames should be continued.

Mr. Frederick Braithwaite said, his attention had been directed, for many years, to the quantity of water that could be abstracted from the deep wells under London, more particularly on the north side. He believed geologists were agreed, that on the south side of London there was a fault in the chalk, from which a supply of water could be obtained. This would account for the fact, that at Plumstead, a large quantity of water was pumped daily, without interfering with the supply in a neighbouring well. He had repeatedly stated, that, owing to the fault above alluded to, the south side of London could not be considered as situated in the same field of water as the north side. For fifteen years past, it had been repeatedly and publicly asserted, that the water in the wells at Trafalgar Square was obtained from the chalk, and from no other source. He had accidentally discovered, that instead of being derived from the chalk springs only, it also came from the sand springs. As an argument against the sand springs, and to account for the increased supply of from 100 gallons to 600 gallons per minute, it was stated, that an enlargement of the far-extending fissures of the chalk, was caused by the friction of the water passing through them. To abstract 100 gallons per minute, at the atmospheric pressure, from fissures extending a distance, say of twenty miles, the diameter of the bore pipe ought to be 9 inches, whereas the pipe in use was stated to be only 7 inches in diameter. But when the quantity so obtained was 600 gallons per minute, a pipe, not less than 19 inches in diameter, would be required. Again; the quantity of chalk which must have been displaced by the enlargement of fissures extending over twenty miles, was enormous, yet no account of it had been given. It appeared from the Paper, that a tunnel was driven from the well in Trafalgar Square to that in Orange Street; but it ought also to have been added, that, owing to the want of proper precautions in driving this tunnel, the sand springs burst in and nearly drowned the well sinkers. The Paper also stated, that the blowing of the sand arose from the 'hugging' of the pipes whilst being driven through the clay, in consequence of which, the screws became detached, and a quantity of sand fell in through the

screw holes. But it was not until sand had been pumped, for several days, into the cisterns of Buckingham Palace and elsewhere, that the fact was discovered. The blowing of the sand was caused, as he had predicted, by excess of pumping over a limited area. There was nothing exceptional in the case of this well; it was neither more, nor less, than an ordinary sand-spring well, from which Buckingham Palace, the Government Offices, and the Baths and Wash-houses, were supplied with water highly impregnated with saline matter.

Mr. Braithwaite then called attention to other Tables and diagrams, prepared by him since the commencement of the discussion. The first contained different analyses of the well water in Trafalgar Square, as reported by Mr. Dugald Campbell, by the College of Chemistry, and by Dr. Clark. According to Mr. Campbell, the number of grains of saline matter, omitting the salts of potash, was 58·85 per gallon, whilst the analysis of the College of Chemistry, made subsequently to that of Mr. Campbell, showed the number of grains to be 69·9 per gallon, being an increase of 11·05 grains. At a previous discussion upon this subject,[1] Mr. Campbell maintained, that there had been an absolute decrease of saline matter. The error arose from the omission of the 13·67 grains of sulphate of potash, as shown in the analysis of the College of Chemistry. Dr. Clark reported, that this water contained 79·8 grains of saline matter per gallon; and he further stated, that by boiling this water, the bicarbonate of soda it contained, became carbonate of soda, which would act medicinally on the kidneys. Other Tables exhibited analyses of the real chalk water at Tring and at Watford, and that supplied by the water companies; they were found to contain from 14 grains to 19 grains of carbonate of lime, with a trifling quantity of other saline matter, per gallon. The surface level at Messrs. Combe and Co.'s well was 74 feet, at the Orange Street well it was 55 feet, and at the Trafalgar Square well only 43 feet above Trinity high-water mark, or 31 feet below Messrs. Combe and Co.'s well, which would account for the water standing in the Trafalgar Square well, so much nearer the surface; and it was due to that cause, and not, as had been erroneously stated, to the extraordinary strength of the springs. In December, 1844, the level of the water in the Orange Street well was 48 feet below Trinity high-water mark, and in December, 1847, 66 feet, showing a loss of 18 feet of water in the short space of three years; whereas the level of the water in Messrs. Combe and Co.'s well at those periods was, respectively, 61 feet and 69 feet below Trinity high-water level, or a loss of only 8 feet. It should further be observed, that the level

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xiv., pp. 519, 520, and 522.

he had given was the average of one month's gauging, whereas that of the Author was only a single gauging; but if the gaugings had been taken simultaneously in the two wells, there was no doubt, that the levels of the water would have been the same.

Mr. HOMERSHAM said, that in different publications upon the subject by Mr. Tabberner,[1] and Messrs. Easton and Amos, it was admitted, that there had been variations in the level, for after a heavy rainfall, or much snow in the winter, or a very wet season, the water in the wells increased in the following spring, and under opposite circumstances, the level of the water fell; but this did not controvert the fact distinctly stated in the Paper, that the water in the Trafalgar Square well stood, in December, 1858, at the same level as in December, 1847, although large and increasing quantities of water had, during that period, been daily pumped from it. He had, since the opening of the discussion, received a letter, confirming the statement he had already made, from Mr. Dugald Campbell, who said:—"I have examined chemically the water of the Trafalgar Square wells, on three different occasions, between the years 1850 and 1857, and each time I have found a decrease in saline contents, altogether amounting to rather more than 7¼ grains per gallon. Combe, Delafield, and Co.'s well water I examined in 1845, and again in 1850; on the last occasion, there was a decrease in saline matter of rather more than 8¼ grains per gallon." With regard to the statements, as to the general and permanent depression of the level of the water, in the wells sunk into the chalk in the north of London, it was advisable, that the situation and particulars of the wells, in which this had been noticed, should be given, and the quantity of water daily pumped, as also the manner in which the observations were made. Unless the assertions were thus corroborated, not by an isolated instance, but by numerous examples, no weight could be attached to them.

In the Paper read before the Institution in 1842, it was stated, that when the water level in the Colne, at Watford, was unduly raised by heavy rains, a simultaneous effect was produced in the chalk wells of London.[2] In 1852, Mr. Homersham personally examined several wells in London, in order to test the accuracy of the statement, but he was unable to detect any trace of evidence in support of it, and he believed that idea to be purely imaginary.

The Reverend Mr. CLUTTERBUCK had been much surprised at the assertion, that the Trafalgar Square wells formed a notable

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[1] *Vide* "The Past, the Present, and the probable Future Supply of Water of London." By John Loude Tabberner. London, 1847. And "A Letter to the Editor of the 'Daily News.'" By Messrs. Easton and Amos; dated 5th of December, 1849.

[2] *Vide* Minutes of Proceedings Inst. C.E., vol. ii., 1842, p. 158.

exception to the variations and depressions, which had taken place in the other deep wells of London. On reference to the discussion on the Paper by Mr. Barlow, read before the Institution in 1854, he found Mr. Homersham to have said:[1]—"Now on the other hand, Messrs. Easton and Amos deliberately stated, that the level of the water, in the well near Trafalgar Square, was quite as high now as when the well was first sunk, ten years since." That assertion could not be reconciled with the Paper now under discussion, in which it was allowed, that there was a difference of 18 feet between the levels of 1844 and 1847; consequently, within the period alluded to in the extract. The statement also, that the wells at Plumstead had not affected the level of those in the neighbourhood, had been distinctly denied by Mr. Dickinson. With regard to the general statements Mr. Clutterbuck was supposed to have put forth without adequate foundation, he would content himself with saying, that, when possible, he had personally taken the measurements on which he relied. He was not aware, that he had ever stated, that the wells in the chalk to the north of the Colne, in Hertfordshire, were gradually and permanently losing their water. He had been told, that such was the case; and by one gentleman in particular, who was, he believed, about to give evidence before a Committee of the House of Commons to that effect, stating that he had noted a defalcation of water to the amount of 70 feet, in a certain well in Hertfordshire. But Mr. Clutterbuck advised him to have patience, and the water would, eventually, return; accordingly, in the notable year 1852, in which Mr. Dickinson registered 41·14 inches of rainfall and 14·63 inches of percolation, through Dalton's gauge, the well in question, with others, regained its water, and the springs and rivers were filled to overflowing. He was convinced, that the same effects would always be produced, on the recurrence of a year like that of 1852. There was also an instance, in the north part of London, of a well,—that belonging to the New River Company,—which stood in 1840, at 110 feet, and sank in 1850, to 124 feet; or 33 feet, and 47 feet below Trinity high-water mark, respectively. It was by observing the variations in this well, that he was enabled to tell, when pumping was, or was not going on, at Reid's Brewery.

The year 1847 was that fixed upon in the Paper, to be compared with December, 1858. Now 1847 was a year in which the percolation of water was very limited; the water level was, therefore, unusually depressed. The register of percolation, through Dalton's gauge, was entirely blank from February to December in that year.

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xiv., p. 83.

He deliberately asserted, that the water question was not to be dealt with by searching after hidden sources of supply, but by taking the water which showed itself above ground. If artificial means were resorted to for the use of towns, the apparent purity of the water might attract a population; but the failure of the sources of supply from exhaustion, might endanger its being, at some future day, deprived of water. The water question assumed, every year, a more serious aspect, and he felt certain, that if it was tampered with, mischief might easily be done, which could never be repaired.

He wished to direct the attention of the Meeting, to Brighton, which was peculiarly situated. The outfall of the chalk water was into the sea; in taking the water, therefore, from the chalk at Brighton, no streams were affected, and no injury was done, except to the wells. Large quantities of water had been pumped up there; in the last year, however, the supply had considerably diminished. Many years ago, he had measured the wells in Brighton, and he had since had the measurements of others, taken about four years ago, supplied to him. On visiting those wells in February last, he found many domed over, and others filled up; in some there was water, but several were perfectly dry. Between the last-mentioned periods, the water in a well near the Cavalry Barracks had sunk 50 feet, and one within the barracks had lost 42 feet and was hopelessly dry. This was also the case with two wells, one of which had lost 31 feet, and the other 40 feet; in a third, nearer the sea, there was a defalcation of 33 feet; and in another, in the town itself, though still containing water, there had been a loss of 25 feet. After such instances, it would be most imprudent to venture on supplying London, from wells in the chalk. The only serious and permanent defalcation of water to be feared, in the chalk districts, was from the exhaustion produced by pumping water from shafts and wells.

Doubts had been attempted to be thrown upon the assertion he had formerly made, that when the water level near the Colne was suddenly raised by heavy rains, a simultaneous effect was produced on the chalk wells in London. He maintained such to have always been the case; for the same cause that affected the Colne, affected the wells also. He did not say, that because the Colne rose, therefore, the wells rose; but that when the Colne rose, the wells rose also.

Referring again to the Trafalgar Square wells, he said, it would have been more satisfactory if gaugings had been made daily, or weekly, and if these records had been incorporated in the Paper. As it was a Government establishment, such a register ought to have been kept. As to the alleged capability of the wells to furnish 600 gallons per minute, he should be glad to know, how

long that rate could be maintained. He had repeatedly given warnings upon this subject, and he had the satisfaction of knowing, that his advice had, on many occasions, been useful to those by whom it had been sought.

Mr. HOMERSHAM inquired, whether the New River Company's well in the Tottenham Court Road was the only one upon which Mr. Clutterbuck founded the assertion, that there was a gradual depression of the water level in the north of London.

The Reverend Mr. CLUTTERBUCK replied, it was the only one of which he had the daily measurements. He might mention, in addition, that Messrs. Reid and Co.'s well was known to have been considerably depressed, as also those of Messrs. Meux and Co. and Messrs. Combe and Co., to the latter of which allusion had already been made during the discussion.

Mr CHARLES MAY could carry the comparison between the depth of the chalk at Colchester and Harwich, and high-water mark, as far as Ipswich, where he superintended the sinking of a well at the works belonging to his own firm. The level of the chalk was about high-water mark, or between 60 feet and 70 feet above that of Harwich, thus showing, that the dip of the chalk was in that direction. There was an abundant supply of water in the chalk at Ipswich. There was a large tract of rising country behind, and the chalk cropped out on the upper side of the Orwell, into which ran numerous streams of fine water. He had no doubt whatever, of the depression of the water in the wells of London. In Cowper Street, City Road, the pumps of a well had been twice lowered since 1832, the water level having sunk, at least, 30 feet, though the quantity of water abstracted was always the same.

Mr. HAWKSHAW, V.P., said he was called upon, some years ago, to report upon a scheme for supplying London with water from Watford, by sinking a large well adjacent to the River Colne, and he then found, as appeared to be still the case, that there existed some misconception upon what he considered to be a very simple question. Water could not be pumped from wells sunk into the chalk, or into any other water-bearing stratum, beyond certain quantities, without affecting the level of those wells. This would be evident upon a little consideration. Subterranean reservoirs, as he might, perhaps, be permitted to call them, were similar to all other reservoirs, and followed precisely the same laws. If a well was sunk into a subterranean reservoir, into which the water happened to come in faster than it was pumped out, that reservoir would remain full; that is to say, it would continue at the precise level which happened to be determined by the natural point of overflow, or escape. But if the water was pumped out faster than it came in, then the level must, of necessity, be reduced. This rule would apply to all wells, whether under London, or else-

where. A certain given quantity of water only could be obtained from the chalk; whenever that quantity was exceeded, the level of the reservoir, from which the water was pumped, would be lowered. He thought a part of the confusion that seemed to prevail on this question, arose from the disposal of the rainfall which it was usual to make, and which had been repeated during the discussion; that one-third was disposed of by evaporation, one-third by the rivers, and one-third by absorption, or infiltration, and that this last portion alone was available for pumping. Now there was no such thing as infiltration in that sense; vegetation absorbed a certain portion of water, and another portion sunk into the ground. But it was evident, that so much of the rainfall as sunk into the earth, and was not taken up by vegetation, or by evaporation, merely passed below the surface again to run out elsewhere, if not immediately into the sea, then into streams, or rivers; consequently, the water which flowed along the streams and rivers, or found its way into the sea, must be the measure of that portion of the rainfall which penetrated the ground by infiltration. He was surprised, therefore, to find it was still considered possible to sink a well into the chalk, and pump from it an unlimited quantity of water, without affecting either the level of the well, or the quantity carried off by the rivers. He did not dispute the statement, that there were places where large quantities might be pumped without lowering the level, because there might be, at those places, a much greater influx than the quantity abstracted; but there was no water-bearing stratum anywhere, from which it was not possible to pump such a quantity of water, as would gradually exhaust it. In some cases, this might be a slow process, because, in addition to the annual quantity obtained from infiltration, a supply might be drawn from water, lying below the level of what might be termed the natural outlet, and accumulated there during long periods of time.

Mr. Rawlinson agreed with the explanation just given, as to the philosophy of water-bearing strata; for there could be no fresh water upon the surface of the earth, nor in the subsoil, which was not due to evaporation from the ocean and other water surfaces; consequently, it was only the volume of fresh water which had been taken up by the atmosphere, which was returned to the earth.[1] Springs were the lips of reservoir basins in the substrata, out of which fresh water poured. Erroneous notions had been entertained, as to the depth at which water was to be procured.

[1] It has recently been ascertained, that the salt water of the ocean, when passed through considerable thicknesses of sand, or of sandstone rock, is filtered, and becomes fresh. But as the surface of the land is, necessarily, above the level of the ocean, and the substrata are supplied from the surface, the filtration from the ocean to the land must be very limited.—R. R. February, 1862.

Many persons imagined it was only necessary to bore deeper to obtain a greater supply; but nothing could be more fallacious. In the new red sandstone, the coal measures, the chalk, and other geological formations, the great volume of water existed in the strata, at a depth of from 300 feet to 900 feet. He was acquainted with coal shafts, in which an immense quantity had to be tubbed out between those depths, but below 1,000 feet very little water was found; indeed, in some very deep coal pits, water had to be sent down to lay the dust of the roads along the workings. Similar instances were to be met with in the coal pits at Pendleton and Monkwearmouth, and in those on the Duke of Newcastle's estates near Worksop. Deep well-water was also, generally, of bad quality, because it contained an excess of mineral matter. He could confirm the statements and warnings of Mr. Clutterbuck, as to the caution Engineers should exercise in relying, for large communities of people, upon a supply of water from wells. Ancient Rome, and New York, were originally supplied with water from wells; Liverpool was partially so supplied at present; and Manchester was originally supplied from wells in the alluvium and new red sandstone. Yet Rome found it necessary to erect numerous aqueducts, to bring into the city a volume of water equal to the amount of 350,000,000 gallons per day; New York poured in 30,000,000 gallons per day; Liverpool, from 12,000,000 to 20,000,000 gallons per day, in addition to that supplied by the wells. In Manchester, they had also resorted to a surface supply, and were furnished with from 10,000,000 to 20,000,000 gallons per day. In all those cases, the local wells had to be abandoned, or to be largely assisted from sources where the water was at the surface; and that was the only safe method of water supply for large communities. At the same time, wells should not be wholly repudiated for small populations, who could not afford the expense of bringing water from long distances.

With regard to sinking wells near the sea coast, the failure at Harwich should not deter Engineers from making attempts in that direction, but should lead them, before sinking, to examine fully into all the natural conditions of the locality. At Worthing, a well had been sunk, the surface of which was about 30 feet above high-water level, and was situated at less than a quarter of a mile from the sea coast. The surface water was tubbed out by cast-iron cylinders to a depth of 70 feet, and then the chalk was bored into for a further depth of 295 feet; the full depth of the well was thus 365 feet. Fresh water was pumped from this well, and no diminution had as yet taken place, nor was the water in any degree salt. The quantity pumped, however, was only about 150,000 gallons per day, but the strata of the district were capable of yielding a much larger supply. There was another

question involved in pumping from chalk, or limestone, or other similar strata; those strata must gradually waste away. Taking the average degree of hardness of the water at 16 grains per gallon, in every 1,000,000 gallons, there was raised more than a ton of carbonate of lime, or chalk. Whether the water was taken from a river, or from a well, the quantity of solid matter was the same. Taking only 80,000,000 gallons of this water, although it was really nearer to 100,000,000 gallons, as the daily supply for London, the total contents of solid lime, or chalk, would be 29,794 tons per annum, or more than 81 tons per day.

It was stated in the Paper, that the fountains in Trafalgar Square were inflicted upon the public, because it was found they could be supplied with water, "without cost." Such a consideration ought to have had no weight with the Government. The fountains and basins brought ridicule on the national taste; they were of no public use, and certainly, they were not ornamental.

Mr. Amos could vouch for the perfect accuracy of the contents of the Paper. He had not contended for theories, nor had he expressed any opinion as to the quantity of water which might be derived from the chalk formation, for the supply of London. Neither had he said, that the quantity of water in the springs of the Trafalgar Square wells, had suddenly increased from 100 gallons to 600 gallons per minute. In the first instance, 100 gallons per minute were thought sufficient; when a larger quantity was required, 300 gallons per minute were obtained; and now 600 gallons per minute were pumped. He had stated in the Paper, that the abstraction of that quantity had lowered the water 24 feet, but beyond that point, the level could not be depressed. In reply to the remark, that a daily record of the height of the water ought to have been kept, he stated, that the contractors both for sinking the wells and for working them, had, during eleven years, taken daily records of the height of the water. He had not thought it desirable to introduce long columns of figures into the Paper, but had simply given the highest and lowest levels at which the water stood, in each year, during that period.

Mr. Locke, M.P.,—President,—in closing the discussion, said, some observations had been made which materially simplified this question, and which were entirely in accordance with his own experience. Most Engineers who had been engaged in tunnelling through the chalk, must have observed, that after several days' rain, the water percolated through, until it reached the level of the tunnel, which, from being perfectly dry, became wet, the water dropping from the roof and sides on to the floor of the tunnel. As the percolation continued, the water level descended, until the roof, sides, and floor became perfectly dry as before. This perco-

lation would continue until the water reached the level of its natural outfall.

He had often sunk wells into the chalk, and he had always found a variation in the water level. This fact, however, would not be conclusive in cases where water was being drawn from wells, much below the natural outfall, or the level of the sea. In those cases, he apprehended the rise, or fall would depend on the extent of water-bearing strata, under the influence of the absorption caused by pumping.

November 22, 1859.

JOSEPH LOCKE, M.P., President,
in the Chair.

The discussion upon the Paper, No. 1,002, "On the Government Waterworks in Trafalgar Square," by Mr. C. E. Amos, occupied the whole evening, to the exclusion of any other subject.

POOLE'S PARALLEL-MOTION SAFETY-VALVE.

After the Meeting, Mr. John Poole exhibited and explained his Parallel-Motion Safety-Valve.

It was pointed out, that the ordinary valve simply rested on its face, or seat; its vertical, or upward motion being guided by a spindle on the lower side, passing through a bar, or feathers in the steam pipe. The area of the discharge pipe was thus reduced one-third, and in some cases, as much as one-half. This valve was pressed upon by a weighted lever, moving on a centre, or hinge on one side. When in a state of rest, the lever and the centre of the spindle were at right angles to each other; but as soon as the valve rose, the angle became acute. This brought an unequal load upon the valve, and caused friction, inducing a tendency in the spindle to twist, and in the valve, to jam, or stick. The guide spindle, being below the valve face, was also liable to be corroded by foul, or dirty water, and was exposed to unequal contraction and expansion. It was likewise found, that these valves, when out of order, invariably leaked on the side nearest the hinge of the lever.

In the Parallel-Motion Safety-Valve, the spindle being on the upper side, the seat, or face was flat, and the discharge pipe was free from interior incumbrances, so that less leverage and weight were necessary. The spindle passed through a guide above, and the parallel motion was attached to the centre of the spindle, on which the valve was hinged. It was shown, by a sectional model, that the radial action of the lever did not control the vertical action of the valve, which, therefore, could not jam, or stick in its seat.

November 29, 1859.

JOSEPH LOCKE, M.P., President, in the Chair.

No. 1,005.—"On Arterial Drainage and Outfalls."[1] By RICHARD BOXALL GRANTHAM, M. Inst. C.E.

IN the Address of Mr. Simpson, delivered on the 10th of January, 1854, on taking the Chair for the first time after his election as President, it is remarked, in alluding to the subject of Land Drainage, that "there has been less attention paid, in the majority of instances, to the question of outfall, as single farms and even single fields could be operated upon, at the pleasure of the owners and occupiers. The experience of recent wet seasons (1852 and 1853) has, however, proved, that large tracts of upland have been drained, to the detriment of lower levels; it has also become evident, that arterial drainage, in many agricultural districts, demands more attention, than it has hitherto received, and that the trunk lines, or the principal watercourses, and the fields contiguous to them, will be liable to be as constantly flooded in wet seasons, as they have been during the last two years, to the great injury of the pasturage, and the serious detriment of all farming operations in low lands, if measures for the arterial drainage and for the improvement of the trunk lines, or principal watercourses, continue to be disregarded. The obstructions of brooks and streams, arising from milldams, and from artificial, as well as natural weirs, applied to exclusive uses and to the irrigation of particular and comparatively unimportant properties, are too frequently maintained, to the disadvantage and injury of large tracts of land."[2]

The foregoing extract accurately describes the general state of many important districts, in which property to a large amount is rendered totally useless. In the present improving and progressive state of agriculture, both arterial and subterranean drainage, but especially the former, demand the particular attention of Civil Engineers, as it is only through that body, who in their daily

[1] The discussion upon this Paper extended over portions of four evenings, but an abstract of the whole is given consecutively.

[2] *Vide* Minutes of Proceedings Inst. C.E., vol. xiii. pp. 200-1.

avocations are accustomed to take enlarged and comprehensive views of such questions, that the subject can be properly canvassed, and some efficient plan of proceeding be devised and adopted. The skill of the Engineer will be, however, comparatively useless, unless aided by the power of the Legislature.

The Author is so impressed, chiefly from his own practice and experience, with the importance of this subject, that he is confident a vast amount of good will result from the establishment of effective legislative powers, and that it will afford a comparatively new field for the exercise of professional skill and ability. These considerations have induced the Author to bring the subject before the Institution, in the hope, that it may be fully discussed, and thereby attract public attention, with a view to the full recognition of its importance, and the necessity of adopting some general legislative measure, giving facilities by which arterial drainage and outfalls may be carried out, on a comprehensive plan, and be effectively maintained in working order.

It is proposed, first, to call attention to some of the evils arising from the want of a combined system of operation; secondly, to give an account of the existing impediments which prevent the adoption of arterial drainage; thirdly, to describe the class of works necessary to be carried on; and lastly, to point out some of the leading principles in the construction of drainage works, by which the object in view may be accomplished.

There is, perhaps, scarcely a district in this country where one of two conditions does not exist: either the lands cannot be drained at all, or they are injuriously affected by the drainage of those above them. The first of these cases is exemplified in those districts lying between the sources of streams, and extending for some distance towards the natural outfall; so that the owner of an estate, situate between those limits, cannot legally straighten, or deepen the stream, or river running through the estate, and thereby drain his land, because he would, by so doing, inundate his neighbour's land lower down the stream. In many cases a single person, who is unwilling to drain his property, may prevent any improvements by adjoining owners, however much they may desire them.

PIPE DRAINAGE.—Subterranean, or pipe drainage has generally been adopted as the first step in the improvement of land. The vast benefits which have resulted from the judicious application of this system will, undoubtedly, lead to a great extension of it. But even on its present scale, in addition to the field drains and ditches being better cleared out, it has already created a large increase in the quantity of water flowing down rivers, brooks, and minor streams.

The effect has been, that the water is discharged in a shorter time than formerly, causing more frequent floods, the brooks and minor streams being, in numerous instances, insufficient to convey away the large quantities of water which so suddenly flow down; and, at other times, the rivers and streams contain less water than formerly; in many cases, not sufficient for the ordinary supply of the country, or of the towns which may be dependent upon them.

To give some idea of the increase in the extent of pipe, or under-ground drainage within recent years, the following circumstances may be quoted. About ten years ago, power was given, by Parliament, to the Government, to lend £4,000,000, under the sanction and control of the Inclosure Commissioners of England, for the drainage of land, and for erecting and repairing farm buildings, &c. Subsequently, private drainage companies have obtained similar powers, subject to the control of the same Commissioners, and up to this time there have been expended by these means, in the subterranean drainage alone of about 800,000 acres of land, a sum of upwards of £4,000,000. A large quantity of land has also been drained by the Crown, by corporate bodies, and by private individuals, the exact amount expended in which it is impossible to ascertain, but it may be estimated at double the sum previously named. There still remain large tracts of land that require to be so drained, and from the beneficial effects hitherto produced, an annually increasing extent will, probably, undergo the same treatment. It may be imagined, that if, from the above number of acres alone, the water falling upon the surface can now be run off, in the course of a few days, to the arterial drains and outfalls, instead of slowly trickling through the soil as before that system of drainage was applied, how absolutely imperative it is, that provision should be made to carry off the water in the most direct and efficient manner, and that, in many works executed for the purpose, there should be ample allowance to meet a much larger flow of water.

Mr. Bailey Denton, (Assoc. Inst. C.E.,) in his Paper, "On the Progress and Results of the Under-drainage of Land in Great Britain," read at the Society of Arts in December, 1855,[1] gives full details of what had been done up to that time, and of the probable amount that would, at some future day, be required. There was no particular reference to arterial drainage and outfalls, beyond the expression of an opinion, that the main and tributary outfalls throughout the country must receive attention, as soon as possible, and that provision should be made on an effective scale.

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[1] *Vide* "Journal of the Society of Arts," vol. iv. p. 45.

MILLS, WEIRS, &c.—Another cause of the difficulty of draining land is the existence of mills, weirs, dams, and other obstructions in rivers, as well as their crooked and confined channels; all of which impound the water upon the uplands, to the injury, in some cases, of ten, twenty, and even fifty-fold the value of the mill, or property maintained by the dams. Another question to be dealt with is, that public roads cannot, in all cases, be interfered with, to admit of better outfalls; the existing culverts, or bridges, being rarely either sufficiently deep, or capacious, so as to admit of the application of an arterial system of drainage.

The other part of the subject,—the injury which lands suffer by being inundated by the drainage of the uplands,—is as extensive as that already alluded to, and is attributable to nearly the same cause,—the want of combination among the possessors of property in executing land-drainage works, the vast expense of which would otherwise be entailed upon single individuals. In some cases, too, it is almost impossible to form sufficiently capacious channels, and outfalls to carry off the surplus waters, and it is always a hardship, that one person should be able to improve his position at the expense and annoyance of others. This is strongly exemplified by the experience of the drainage of towns, under the Public Health Act, where, at the commencement, no provision was made at the outfall, for the disposal of the sewage; showing a want of forethought which should, in future, be avoided in land drainage, before any general and complete system is undertaken. Both these cases are well illustrated by the instance which Mr. Simpson has kindly allowed to be referred to—that of a proposed drainage in the vicinity of Wareham, in Dorsetshire.

WAREHAM.—In 1855, Mr. Simpson was consulted by the Trustees of the Right Honourable the Earl of Eldon, as to the best means of draining and improving the marsh land belonging to the estate, in the neighbourhood of Wareham. This town is surrounded by marshes, which are stagnant during a great portion of the year. The trustees, being owners of house property, were also anxious on that account to improve the sanitary state of the locality. The entire marsh land of this district is about 3,000 acres in extent, of which it was proposed to include 2,550 acres. It is situated, chiefly, on the borders of the North and South Rivers, extending from below the confluence of these rivers, in the Wareham Channel, to about four miles above the town. The breadth of low land in both valleys averages, together, about three quarters of a mile; and at the lower end, near the Wareham Channel, the width is rather more than one mile and a half.

The soil is principally alluvial deposit, brought down by the rivers during floods; and where isolated attempts have been made to drain small portions of it, evidence has been afforded of its great fertility. The whole of this land has, at some remote period, been reclaimed by the neighbouring landowners, from the estuaries of the North and South Rivers. Small embankments of mud have been thrown up on each side of the river channels, following their circuitous course along the muddy foreshore; the materials being obtained by excavating a side ditch close to the embankment. The lower drainage is provided for by other ditches, (acting also as fences), which communicate with trunks, having sluice flaps fixed in the embankment at various points, for discharging the drainage into the rivers at low water of every tide. No attempt has ever been made to divert the upland streams, which frequently do great mischief during floods, and permanently maintain the water in the ditches at a much higher level, than it would otherwise remain from the tidal drainage. These works have existed many years, and are kept in tolerable repair by the respective landowners.

The range of tide in the Wareham Channel, into which this district drains, does not exceed 6 feet on the average, during springs, and $3\frac{1}{2}$ feet during neaps. The general surface of the marsh land on the lower side of the town, varies from 2 feet to 3 feet below high-water mark of spring tides. Above Wareham it rises gradually inland, until, at Holme Bridge, on the River Frome, one mile and a half from Wareham, it is about 12 feet above high water. At East Stoke Mill, about three miles from Wareham, the land is 25 feet above that level. This affords facilities for drainage by gravitation, and the proposed works were arranged so as to discharge by outfalls, continued down the side of the river, to a level sufficiently low to prevent the lands being injured by backing up the water during floods. It was also intended, that the river should be properly embanked, to confine the flood waters to its channel.

At the lower end of the marshes, below Wareham, where the great bulk of the land is situated, the surface is only $2\frac{1}{2}$ feet above low water of neap tides, which is the maximum power of the present system of drainage at such periods; and if 1 foot is allowed for accumulation in the ditches, between the tides, the average depression of the drainage will be only 18 inches below the surface of the land during neap tides. This is totally insufficient for the outfall. In order, therefore, to effect the complete drainage of this part of the marsh land, and to depress the water in the ditches to a permanent level of about 3 feet below the tide, so as to afford a clear outfall for the under-drainage pipes, (in-

tended to be laid at a depth of not less than 3½ feet below the surface,) it was obviously necessary to resort to mechanical aid. Mr. Simpson recommended, that a small steam engine should be provided, to be used in connection with upper and lower reservoirs. These reservoirs were to be formed out of the old river channel, which could be made available for the purpose, at a trifling expense. This arrangement of reservoirs forms an important feature of these plans. It was proposed with the object of reducing the pumping lift to a minimum, and of economising the cost of construction and of working, to the greatest possible extent. The lower reservoir receives the accumulation of any sudden fall of rain beyond the power of the engine, and prevents, by the extent of surface, any material rise in the water level of the ditches, or dikes. The upper reservoir discharges the accumulated drainage at low water, and then receives the continued discharge from the engine between tides, at a level not much above low water. This would, otherwise, have to be pumped either to high-water line, or to the level of the tide for the time being, as is generally the case in similar districts where pumping is resorted to.

In the event of its being deemed advisable to promote a Bill in Parliament, or in case of any general Act being introduced, which could be made available for carrying out large drainage projects, it was recommended, that in addition to perfecting the drainage of the Wareham district, comprising the lands of East Stoke, Carey, Keysworth, Arne, and Middlebere, provision should be made for reclaiming upwards of 500 acres of mud land from Wareham Harbour, at present covered with about 2 feet of water at high-water spring-tides. It may be observed, that the straightening and deepening of the river below Wareham Bridge would, no doubt, greatly improve the navigation, without imposing any charges, or dues on the shipping, as the expense of the river improvements would not be so onerous on the landowners, as to induce them to seek relief by a charge on the navigation. The intended new works comprised several cuts, for straightening and improving the channels of the North and South Rivers, for diverting the upland waters from the marshes, and for conveying the lower drainage waters to the pumping station near the South River Head, together with embankments at Middlebere and Wareham Bays. No ditches were to be excavated near the side of the new embankments, for the purpose of procuring material for their foundation, as sufficient earth might be obtained from the adjoining high ground, and from the partial excavation of the reservoirs. The existing ditches were to be filled up, where the present embankments were retained, as it was thought their strength was much impaired by the ditches at the foot of the slope. These ditches also en-

couraged vermin, whose burrowing frequently caused leakage through, and ultimately a breach in, the embankment. The lower drainage was to be lifted by a steam engine of 20 H. P., with upper and lower reservoirs for containing the accumulated drainage. There was to be a syphon pipe under the North River, for conveying the drainage from the Keysworth lands, together with sluices for discharging it into the Wareham Channel, near the North River Head, and everything requisite for the complete and perfect drainage of the district, under legislative powers.

The cost of carrying out this general scheme was estimated at £22,000. It would involve an average annual charge of 7*s*. per acre on the whole district, to provide for interest of capital expended, and for the cost of working and maintenance, after deducting the annual value of the reclaimed land.

In case the attempt to introduce a general scheme should fail, in consequence of the absence of unanimity on the part of the landowners, or the want of a General Act of Parliament, Mr. Simpson deemed it advisable to point out the next best course, viz., the adoption of some limited plan, providing, chiefly, for Lord Eldon's land, and which should be capable of being carried out, as much as possible, independently of other proprietors. This alternative obviously involved considerable difficulty; because the relative situation of other lands, belonging to dissenting, or unfavourable owners, rendered them likely to be benefited at Lord Eldon's expense; and because no complete, or efficient scheme could be carried out, which did not provide for the alteration of the navigable part of the river below Wareham,—a proceeding not unlikely, in the absence of Parliamentary powers, to meet with some opposition from the public, and from a few persons who pertinaciously insisted, that the river should be maintained in its present course. Having these difficulties in view, four alternative plans were submitted, termed private projects Nos. 1, 2, 3 and 4,—in addition to that called a public project,—so as to enable Lord Eldon's trustees and agents to select that plan which would be least likely to interfere with the property of opposing owners, and which would best meet the circumstances of the case, after negociating with the parties interested. Regard was also had to the probable ultimate extension of the adopted plan, as a more general scheme of which this would then form an integral part, without involving any material additional outlay, for alteration and reconstruction of works.

The following statement gives the comparative estimated cost of the several propositions:—

WAREHAM.—DORSET.

DRAINAGE OF THE ARNE ESTATE AND ADJACENT PROPERTIES.

STATEMENT of the various DRAINAGE PROJECTS, COMPARATIVE COST of WORKS, MAINTENANCE, ETC.

PROJECTS.	Land Improved.	Land Reclaimed.	Total Land in Drainage District.	Land Drained, the property of Lord Eldon.	Total Outlay for Construction of Works.	Total Annual Charge per Acre.
	Acres.	Acres.	Acres.	Acres.	£.	s. d.
PUBLIC PROJECT.—East Stoke, Carey, Keysworth, Arne, and Middlebere Districts	2,050	500	2,550	1,300	22,000	7 0
PRIVATE PROJECT.—No. 1. Wareham, Bestwall, Giggers, Isle, Arne, and Middlebere Districts	840	400	1,240	1,200	13,310	7 7
Ditto No. 2. Wareham, Bestwall, Arne, and Middlebere Districts	730	190	920	900	9,944	10 11
Ditto No. 3. Whitefield, Arne, and Middlebere Districts	500	180	680	680	6,479	9 6
Ditto No. 4. Ditto Ditto	500	180	680	680	6,545	10 4

The reclaimed land is valued at £20 per Acre.

This example embraces nearly all the difficulties and evils which would generally occur in most districts, and which it is so desirable should be provided against and remedied.

Having now, in a general manner, referred to the causes of the injury which arises from the present state of things, the next point for consideration is the impediments which exist. These must mainly be attributed to the state of the law, which, as it at present stands, is totally unsuited to the existing and advancing state of society, and to the interests of the holders of property. For while it jealously watches many unprofitable and useless rights and forms connected with property, it as surely prevents the wants and necessities it ought to assist and modify, from being attended to. It has been said, that the powers of the Legislature must aid the skill of the Engineer. But the plans of the Engineer are easy of execution, compared with the removal of the complications which are thrown over the whole question by the law, and these must be removed before any real good can be attained. The few attempts at legislating upon the subject have been ill-designed, and too feeble and timid to grasp the whole question, in an effectual manner. The best measure which has ever been proposed, in the Author's opinion, was the Bill of the Earl of Carlisle, in 1852, which it is to be hoped, with additional provisions, may yet be made to accomplish the great objects of improved arterial drainage and outfalls. The law, at present, prevents arterial drainage being carried out on a combined and comprehensive system, by not allowing a person to deal with his own property in this respect as he best can; neither is it sufficient to allow of certain things being done, in order to facilitate such objects as would enable individuals, or associated bodies, to act for the good of all concerned. In fact, nothing can be effected, until the law is modified and changed, and its powers enlarged and liberalised.

The points involved in this question, which more immediately concern the Engineer, are the straightening and deepening of both internal and tidal rivers; and the removal of mills, dams, weirs and other obstructions, in order to produce uniform inclinations towards the outfalls of streams. The gradients, or inclinations, should be adopted with reference to the soil, through which the rivers flow, to obviate the scouring action of the water on the banks and bottom of the streams. It is also necessary to impound the surplus water, so as to preserve a uniform minimum supply to the channels of rivers at all times, and to provide works for carrying off field drainage, for the irrigation of adjoining lands, for the reconstruction of bridges and culverts under public roads, and for the application of the water to the supply of towns and villages, which, in many cases, may be altogether deprived of supplies by any complete system of drainage.

IRELAND.—The Author conceives, that some allusion should be made to the drainage works which have been executed in Ireland, as they form the best examples of arterial and outfall works in the United Kingdom.

In the year 1846, when Ireland was visited with one of the greatest calamities that can befal a country, the deprivation of food, the Government proposed that, for the sake of giving employment to the people, arterial drainage works should be undertaken, and that the lands should be charged with the cost, "in proportion to the benefit conferred;" the assent of the owners being first obtained to a limited outlay, and the Government lending a certain proportion of the money, and granting the remainder. The urgent necessity that immediate employment should be given, taxed the utmost energies of the Engineers, acting under the Board of Works, who designed and executed the several works with the utmost rapidity; so that in five months and a half, no less than one hundred and one districts were surveyed, and the works planned, estimated, and, with few exceptions, commenced. Owing to this rapidity, many, as might have been expected, were imperfectly and wrongly projected, and the cost, ultimately, much exceeded the original estimates. Subsequently, when the pressure caused by the famine had been somewhat relieved, several of the works were stopped, for want of the assent of the owners to a further expenditure. A Government Commission, consisting of Sir Richard Griffith, Bart., Sir William Cubitt, (Past-President Inst. C.E.,) and the late Mr. Rendel, assisted by Mr. John Clutton, was then appointed to inquire into twelve of the districts. Their Report, which was published in 1853, gives a full account of all that had been done up to that time, describes the extent of the works, and recommends the manner in which they should be completed. In that Report it is stated, that the works exceed 385 miles in extent; the catchment basins comprehending an area of 1,139,182 acres, of which about 77,546 acres were liable to injury by floods.

It is generally admitted, that great benefit has resulted from these works, which were mostly designed upon a comprehensive scale, and would serve as outlets for heretofore pent-up and flooded waters. Large districts, which formerly were always under water, are now entirely freed from it, and capable of profitable use. These drains are, in many cases, sufficiently large to allow an extended area to be discharged into them, at any future time.

The great drawback to the efficient working of this system is, that there was not, at first, so far as the Author can learn, any provision made, by which the works were to be maintained and kept in repair after the first year. Another objection is, that a

large sum of money was expended in works for improving, and in some cases, creating water power, which proved totally useless and inconsistent with the primary object of the drainage schemes.

The following Table, (page 64,) gives the results of five cases, in different parts of Ireland, out of the one hundred and one which were executed; but they afford a fair average of the whole. It shows the area of land drained in each case, the total cost, the original annual value of the lands drained, and the increase upon the annual value; also the rate of the cost per acre, and the annual charge to defray principal and interest.

These drainage operations were principally undertaken under the Acts of Parliament 5 and 6 Vic. cap. 89; 8 and 9 Vic. cap. 69; and 9 Vic. cap. 4; the latter of which was generally called the 'Summary Proceedings Act,' and which was to find employment for a starving population. Other Acts were passed in the following years up to 1850,—to appoint additional Commissioners, to continue 9 Vic. cap. 4, and several for providing additional funds for loans and advances on works of drainage. Many of the provisions which are contained in the above Acts, would serve as excellent precedents for legislation on the subject in England.

DRAINAGES IN IRELAND.

NAME OF THE DRAINAGE DISTRICT.	Area of Lands within One Mile of the Lands Drained, or Improved, belonging to the same Proprietors as the Lands Drained, or Improved.	LANDS DRAINED, OR IMPROVED. Area of Lands Drained, or Improved.	Total Cost.	Original Annual Value of Lands Drained, or Improved.	Increase in the Original Annual Value of Lands Drained, or Improved.	Cost of Works per Acre.	Annual Charge per Acre of Principal and Interest.
	A. R. P.	A. R. P.	£. s. d.	£. s. d.	£. s. d.	£. s. d.	s. d.
District of the Blackwater, in the Counties of Meath and Kildare ..	11,010 1 31	3,827 2 18	12,115 16 6	2,119 1 8	1,034 7 9	3 3 3	4 0
District of Lough Neagh, in the Counties of Antrim, Armagh, Down, Londonderry, and Tyrone.	59,002 1 31	29,625 1 24	156,277 14 10	25,656 2 5	9,953 17 7	5 5 6	6 0
District of Oranhill, in the County of Galway	2,303 2 19	974 0 16	3,871 16 2	260 12 5	315 10 1	3 19 6	5 9
District of Borrisokane, in the County of Tipperary	4,433 3 29	1,517 0 39	10,038 17 11	728 7 10	505 19 5	6 12 4	6 6
District of Shinrone, in King's County and County of Tipperary	5,533 1 4	1,288 3 7	8,209 2 9	..	434 19 7	6 7 4	6 3

Bedford Level.—The next great work of arterial drainage and outfalls, as an illustration of what has been done in reclaiming a large area of country from the effects of stagnant water and floods by drainage, is that of the fen districts, which presents, probably, the largest work of the kind in the world, and to which many of the first Engineers have devoted much time and skill.

This enormous tract of land was probably, at first, an estuary of the Wash, into which the Rivers Witham, Welland, Glen, Nene, and Ouse were discharged. In the north of Lincolnshire, the fens do not extend more than 4 miles, or 5 miles inland; but in the south of that county they are 20 miles wide, and from Lynn to Peterborough, which is the broadest part, they are 30 miles wide. This width is maintained for some miles further south, until arrested by the oolitic elevations of Huntingdonshire and Cambridgeshire. The fens terminate a few miles south of Ely, and the whole length of the district is about 130 miles. With the exceptions of the Lincolnshire Wolds to the north, and a small tract which penetrates it to the south and south-west, the whole fen has nearly one level, which is often beneath that of the sea, especially about its middle and southern parts. Its original condition may be readily conceived from these elementary facts. The water flowing into and falling upon so extensive an area, from elevations too small to impel it onward, would naturally be arrested in a marsh, whose lowest point was midway between the sea and its inland borders. The result was a large fresh-water estuary, which, for many ages, was probably the sole characteristic of the fen.

The principal rivers, forming the present water drains to this district, are the Witham, the Welland, the Nene, and the Ouse. As fen rivers, the Witham and the Welland transport inconsiderable quantities of fresh water to the sea. The more important sewers of the district are the Ouse and the Nene, both of which rise in the same county, and after taking directions nearly at right angles, discharge themselves into the Wash within a few miles of each other. The River Ouse is, probably, one of the most tortuous in the kingdom. Its main branch rises at Gentworth, about 10 miles N.N.W. of Buckingham, which is about 80 miles from Lynn, but it passes over about 160 miles in its course. The River Nene originates in two springs, north and south of Daventry. Its course is easterly to Northampton, where it becomes navigable. The direct distance to the outfall at the sea is 60 miles; but the course of the river is nearly 100 miles in length. At Peterborough it enters the fens, being chiefly conducted through this region by artificial cuts, so that its original channels are, in some cases, hardly traceable. The valley of the Nene is lost 30 miles before it falls into the sea; that of the Ouse extends no further than St. Ives, and runs a course, afterwards, of 50 miles between

that town and Lynn. The valleys of the Glen and the Welland terminate on the borders of Lincolnshire. It will be apparent, that these rivers all seek a common outlet, over lands which are no higher than their beds, and are only prevented by embankments from distributing themselves over the soil. When it is considered how great an extent of country these rivers drain, and what large bodies of water are at all times discharged through their mouths, it is hardly surprising, that the exertions of science and ingenuity have scarcely been sufficient, to keep the fens from relapsing into the general morass from which they seem to have been reclaimed. The extent of country drained by the Wash, includes the entire Counties of Cambridge, Huntingdon, Bedford, Northampton, and Rutland; nearly one-half of Norfolk; one-third of Suffolk; one-half of Buckinghamshire; three-fourths of Lincolnshire; and a small part of Leicestershire; comprising altogether about 5,000 square miles.

Having given the general character of the fens, and of the rivers which discharge into them, the Author proposes to describe the means which have been adopted to reclaim them, and to raise them to their present valuable and flourishing condition.

It is unnecessary to enter into the history of the former works, which were commenced in the reign of Charles I., about the year 1639. For although highly interesting and instructive, they were on a limited scale, affecting, probably, only parts of the fens, and have been superseded by subsequent undertakings, on a more extended scale and with more ample means.

From 1720 to 1750, works were projected, or executed by Vermuyden, Westerdyke, Dodson, Scotton, and Kinderley. It is not requisite, in elucidation of the subject of arterial drainage and outfalls, nor does the Author propose, to enter into minute details of the works which have been recently executed, in carrying out the system of drainage in the fens.

The Bedford Level, (Plate 2,) is divided into three parts, called, respectively, the South, the Middle, and the North Levels. To commence with the SOUTH LEVEL. This division is drained by the Ouse and the Bedford Rivers which, as well as the Well Creek, have been, for many years, variously treated. The first Denver Sluice, placed at the confluence of these rivers, by keeping up the waters of the Bedford River to a higher level, caused all the fens in this district to be flooded. But in 1713, that sluice was carried away. It was then expected, that the tide would deepen the Ouse, and from the increased in-draught of water, give a readier discharge. But in 1720, it began gradually to silt up, and to such an extent did this proceed, that the South Level became more flooded than before. Many proposals were made to remedy this state of things. In 1750, Labelye rebuilt the sluice. But as the

harbour of Lynn still suffered from the accumulations of sand and silt, it was proposed to straighten the Ouse, by cutting off a bend in the river above the harbour. This would have had the effect of reducing the distance from about 7 miles to 3 miles, and of giving a greater depth of outfall. After several years of delay, caused by the opposition to the scheme, an Act was passed, in 1795, to carry out the Eau Brink Cut. It was not, however, until after the lapse of twenty-one years, that this work was commenced. It was opened in 1821, and the effect upon the drainage of the country fully answered the expectations of the Engineers engaged. It not only lowered the low water at its upper end 6 feet, or 7 feet, but it improved the navigation up to, and in, the harbour of Lynn. In consequence, it was possible to lower the cills of the Denver Sluice 6 feet, the effect of which made a manifest change in the South Level. The tide, that before hardly lifted itself in the Bedford River, now penetrates almost to the end of it. That river was considerably deepened, and the channel of the Ouse, formerly so much silted up below Denver, was speedily cleansed, by the increased speed and body of tide that scoured through it. The estimates which have been made, from time to time, for the formation of the Eau Brink Cut, are strange documents now that the actual expense is known. The cost has been about £600,000, and is rated upon the lands drained by the rivers having their outlet into the Ouse, which amount to 250,000 acres, including a portion of the Middle Level.

The next portion of the subject is the NORTH LEVEL. For a great number of years, this vast tract was suffered to drain by the crooked course of the Old Nene River, the internal drains being kept cleared, as far as it was possible, where there was not a good outfall. The consequence was, that the Nene continued to silt up, and became less and less capable of discharging the waters, not only from the back country, but from the lands along its banks.

The first attempt at improving the outfall was proposed by Kinderley in 1721. In 1770 a cut, commencing 5 miles below Wisbeach, was completed; but it was only 1½ mile in length, and only half of that which had been proposed by Kinderley. Whatever benefit may have been derived from this beginning, it tended to prove the principle, that a more extended work would have been more beneficial. It has gone to this day by the name of Kinderley's Cut. Besides the unsatisfactory state of the discharge of the waters of the Wisbeach River, four breaches of the banks occurred between 1763 and 1770. Kinderley's Cut directed attention to the root of the evil, but further efforts were necessary. It was soon found, that the immense sandbanks immediately below the cut, which had been partly cleared away by

its operation, began to accumulate to such an extent as to cause, so early as 1804, great anxiety to the owners and occupiers of land, draining by this outfall, while the navigation to Wisbeach was in an equally unsatisfactory state. Not only did agriculture suffer, and land become of less value, but the navigation was totally destroyed for large shipping, and the trade was chiefly carried on by small craft and by lighters, which conveyed the cargoes to and from the shipping, lying at anchor at Sutton, exposed to immense risk and causing great expense. The agriculturist, the merchant, and the mariner thus experienced great anxieties for their respective interests, from being constantly exposed to loss and expense. At last, the Corporation of the Bedford Level instructed Mr. Rennie to "report his opinion on the Wisbeach Outfall, and the drainage of the extensive washes lying between the two branches of the Nene, as also the North Level, &c."

Mr. Rennie made his Report in 1814, and the levels taken by him showed, that between Wisbeach Bridge and Gunthorpe Sluice, a distance of about 5¾ miles, the fall was only 6 inches; but from Gunthorpe Sluice to Crabhole, a distance of about 5½ miles, the fall was 13 feet. From these remarkable facts, it was evident, "that the high shifting sands, which lie between Gunthorpe Sluice and Crabhole, form one of the great bars to the discharge of the waters of the Nene; and that the levels prove so incontestably where the obstruction lies, that little reasoning is required. If the outfall of the Nene is to be effectually improved, it must be by a new channel, from the mouth of Kinderley's Cut to the level of low water in the bay; and no place seems so eligible, both in point of distance and depth of water, as Crabhole." Mr. Rennie also recommended, that the river should be deepened and widened as far as the Horseshoe at Wisbeach, and a cut be made thence to Rummer's Mills, and thence to Peterborough.

This Report was published about the period of the peace, after the battle of Waterloo; but the wet harvest of 1816 brought so much distress upon the agricultural interest, that it was impossible to impose further taxes at that time for carrying out so magnificent a scheme. The plan lay dormant, therefore, till 1818, when it was revived with increased energy.

About this time it was proposed to build a bridge and make an embankment at Sutton Wash, to establish a direct communication between the Counties of Lincoln and Norfolk. In the interval between 1818 and 1826, nothing was effected, in consequence of the opposition of the town of Wisbeach, to any improvement in the River Nene, as proposed by Mr. Rennie, and to the bridge and embankment, which were also opposed by the agricultural interest. But owing to the perseverance of the Duke of Bedford,

Mr. Tycho Wing, Lord William Bentinck, and others, the Bridge Committee, and the North Level Commissioners resolved upon forming the channel from Kinderley's Cut to Crabhole; together with the bridge and embankment. After much negociation between the above parties, the town of Wisbeach, the South Holland proprietors and others, a sufficient sum of money was procured to carry out the above plans. The Act was obtained in 1827, and after some material alterations and improvements, suggested by Messrs. Jolliffe and Banks, had been adopted, and many difficulties incidental to such a work had been overcome, it was completed. The water was turned through the new passage in June, 1830; but before the scour, required to deepen the new channel, could act with sufficient effect, it was necessary to dam off the old channel. The result was most successful; but the effect of the opening upon the bridge, which was built during the formation of the New Cut, was extraordinary. At the flow and ebb of the tide, large holes were scooped out above and below the bridge, and great fear was entertained of its destruction; this, however, was remedied. The effect of the scour, upon the sides and bottom of the cut, was so great, that it was necessary to protect the banks, with a large quantity of stonework.

The following were the dimensions at the lower end of the New Cut, at Crabhole:—

Width at the top	270 feet
Ditto bottom . .	165 „
Depth	24 „

At the upper part, at Kinderley's Cut:—

Width at the top	200 feet
Ditto bottom . .	135 „
Depth	24 „

or a regular depth of 8 feet below low water. The cost of the Cut, or new channel of the Nene, from Kinderley's Cut to Crabhole, was £200,716.

As soon as this great work was accomplished, the North Level Commisioners set about adapting the internal drains to the new state of things. A new sluice was constructed to discharge the waters of the level into the Nene, the cill of which was laid 5 feet deeper into the old channel than the one which it succeeded; and there was an opening for waterway of 36 feet, instead of 17 feet as formerly.

The main drain in connection with this sluice was formed up to Clough's Cross, a distance of 8¼ miles, 8 feet deeper than the Old Shire Drain, and six times its capacity. From Clough's Cross, the new drains diverge into two lines, called, respectively, the New

South Eau and the New Wryde, which receive the waters from every district of the North Level, including Newborough, Borough Fen, and Great Portsand. When the works were opened in 1834, their efficacy was found to surpass the most sanguine expectations of the promoters. The opening of the Nene Outfall had an extraordinary effect upon the town of Wisbeach, where it added from 10 feet to 12 feet to the depth of water in the river, solely by the action of the scour occasioned by the lowering of the outfall. To accomplish this, Mr. Rennie had estimated, that it would cost, together with the deepening of the river through the town to Rummer's Mills, £56,544, but this expense was nearly all saved by the scour. The increase in the trade of the town of Wisbeach has been equally extraordinary. The tonnage which, in 1829, was 55,040, rose to 63,180 in 1830, the year in which the Nene Outfall was opened; and to 167,443 in 1847, since which time the Author has no further information.

The total sum expended upon the whole of the works has been upwards of £100,000, which has fallen upon the land, and the area drained is 200,000 acres. The cost of the new outfall was £200,000, of which the North Level Commissioners contributed £140,000, in addition to £150,000 expended on the internal drainage, making together £290,000, besides providing for the maintenance of the works. At the time, it was believed scarcely possible, that the agriculturists could bear up against so heavy a burden, but it has been found, that the money has been well spent, and that land, which twenty years previous to 1848, was only worth £5 per acre, would then fetch from £60 to £70 per acre.

The third and last portion of the fen district is the Middle Level. This part of the fens presents a much more complicated system of drainage than the others, having a network of leams, drains, eaus, and rivers, running in all directions, except the proper ones; in some cases at right angles to the outfall, and at others almost in a contrary direction. The principal artery of this area, is the Old River Nene, which takes a very circuitous course. It runs through Whittlesea, Ugg, and Ramsey Meres, and thence to March and Upwell, where it is connected with the Ouse, by a junction with Popham's Eau and Well Creek. It had, for many years past, been a source of contention, between those using it as a navigation, and the owners of land requiring to make it available for drainage. As it was used as a navigation long antecedent to its being adopted for drainage purposes, the navigation had a prior claim. During the continuance of these disputes, the river was gradually being filled with weeds and mud, so that it became useless as a navigation, and little better as an arterial drain.

The remedies which had, in 1795, been applied to the fens, consisted merely in cleansing drains, which had become so grown

over as to be impassable to the waters, repairing where repairs could hardly remedy, and altering in such a manner, that it only made the system still more embarrassed. It was expected, that the forming of the Eau Brink Cut, would have given great facilities to the drainage, by means of a superior outfall; but the benefits were withheld, owing to the opposition of the parties concerned. In 1800, when matters were at their worst, Mr. Rennie was consulted. He proposed a series of catchwater drains, to be carried along the foot of the high grounds, to intercept all the waters that would otherwise have spread themselves over the fens, ultimately to be drained off at great cost and probable injury to the land.

The success which attended the carrying out of this principle in the Lincolnshire Fens, under Mr. Rennie, induced the Corporation of the Bedford Level to request him to make a survey of, and prepare a plan for the general drainage of that level. Almost every great' work which had been undertaken in the fens, was the result of the pressure from loss and misfortune to the owners of land, by bad drainage, floods, and insufficient and ill-cared-for banks. Such was the case when Rennie was requested to make his report in 1808. In the previous spring, thousands of acres had been overflowed, banks had been breached, sluices had been blown up, and damage done, to the amount of, at "least, £1,000,000 sterling." The plan proposed, which was one of the most comprehensive ever brought forward for the relief of the levels, may be briefly described as insisting on the making of the Eau Brink Cut a preliminary necessity, and then surrounding the whole fen with catchwater drains. The two Bedford Rivers were to be converted into one, by a drain carried through the middle of the Wash, from Mepal to Denver, and the Wash itself thereby drained. A new cut was proposed from Whittlesea Mere, in lieu of the Old Nene River and its extensions, to be continued thence to the Eau Brink Cut, and a drain was to be carried to the same point from Grunty Fen. These were the principal works proposed to be made, but the extent of the design, and the estimated expense of upwards of £1,000,000 sterling, so alarmed those, who, by an unfriendly season, had suffered to more than that amount, that this great design was never carried out.

Important as the results were which the making of the Eau Brink Cut had accomplished, many other works were required to second the relief it gave, or promised.

A large portion, amounting to one-third of the Middle Level, is situated along the borders of the Nene, from which an embankment alone separates it. This portion, which was in a wretched state as regards drainage, had to send the floods, that came within a few yards of the Nene, a distance of thirty miles, through crooked

and shallow drains, to gain their discharge into the Ouse. The consequences that followed were, that much of the land was nearly worthless, the least flood inundated it, and reeds and osiers were the only crop, raised upon quagmires and bogs. Many proprietors of this portion, seeing the success of the Nene Outfall and the drainage of the North Level, felt that their own was favourably situated for enjoying the same benefits. There was fertility and prosperity, well-stocked farms, and an abundance of grain and crops north of the Nene; while there was little else but morasses, meres, bogs, reed fields and sterility to the south of it.

In 1836, at a public meeting held at Peterborough, Sir John Rennie, (Past-President Inst. C.E.,) was instructed to re-examine the plans, &c. made by his Father, himself, and others, with a view of re-adjusting them, according to the altered circumstances of the river, by the operation of the Nene Outfall. In 1837, Sir John Rennie reported the defects in the drainage and navigation, and pointed out various methods for removing them. The chief purpose of the promoters of this work was to secure a navigation to Peterborough, for small-sized vessels, and to enclose Morton's Leam Wash. The third point, that of draining 50,000 acres of the Middle Level, was only half adventured on, and was stated with hesitation. Sir John was instructed to consider the question of the Middle Level as distinct from the others, as the proprietors were averse to interfering with the present course of draining into the Ouse. But this, notwithstanding, became the basis of the whole scheme, and it was the destruction of it.

The district proposed to be drained, which contains 50,000 acres, was comprised between the Old Nene and South Morton's Leam Bank. It extends from Whittlesea Mere on the west, to Guyhirne on the east. Running through the centre of this area are two drains in one line, Bevil's Leam and the Twenty Feet River, which Sir John Rennie proposed to excavate, and continue from Guyhirne through Whittlesea Mere to Caldecot, making a branch drain from Pond's Bridge, through the southern portion of the fen, and surrounding the whole, from Standground to Ramsey Mere and Monk's Lode, with a catchwater drain. The estimate for this was £120,000. Since 1841, several Engineers have surveyed and reported upon schemes for improving the drainage of the Middle Level, but none of the plans have been carried out.

It seems, that there were two opinions, or rather two plans, proposed upon the subject of the best outfall for the southern part of the Middle Level. Sir John Rennie strongly advocated that at Sutton Bridge into the Nene, while others were in favour of draining into the Ouse.

The summer, autumn, and winter of 1841 were extremely wet seasons, and the continued heavy rains inundated the Middle

Level. All the rivers were swollen, the mills for pumping from the back drains were totally inadequate to discharge the enormous quantity of water that had accumulated, and the water rose to 14 feet above zero at the Old Bedford Sluice. Denver Sluice was in danger, and banks were torn down by the violence of the torrent.

The proprietors again bestirred themselves, and they determined to consult Mr. James Walker, (Past-President Inst. C.E.,) who was instructed, " that immediate steps should be entered into, for the better drainage of the whole Middle Level, by means of an improved outfall, and by widening and deepening the internal rivers," and " to direct his attention to the state of the River Ouse below Denver Sluice, with a view to consider, whether any and what improvement can be made in that river, to render it more effective for the drainage of the Middle and South Levels:" also " to have regard to the effect which the measures he might recommend would have upon the navigation." Mr. Walker received his final instructions at a meeting of the Committee, at Ely, on the 27th of April, 1842, when it was left to him to report fully upon the subject in all its bearings, and upon the various schemes suggested, which he might consider requisite, for enabling him to propose " the most effectual measure for the better drainage of the Middle Level, having regard to the navigation within that district."

The area of the Middle Level of the fens, upon which Mr. Walker had to survey and report, was about 140,000 acres, exclusive of the high lands about Whittlesea and March. With the exception of these lands, the whole of this vast area was drained by artificial means. This has arisen, partly from the lowness of some parts of the fens, partly from the internal drains not having been adapted to the improved state of the Ouse, and partly from the navigation levels having been fixed too high, to allow of advantage being taken of the recent improvements for drainage.

Mr. Walker, in his Report of 1842, refers to the propositions made by Mr. Rennie in 1809, which have been before alluded to; also to those of Sir John Rennie for draining the Middle Level into the Nene.

Mr. Walker fully discussed the levels and distances of the several rivers and drains, and the schemes proposed by others. He then came to his own proposition, that of separating the navigation from the drainage, and carrying the present rivers and drains over the main drains, which, he suggested, should be made straight through the Middle Level. He proposed three lines of drains for selection, two being alternative lines, but the termini were the same in all. The drain which he finally selected was to commence

at the upper end of the Eau Brink Cut, above the Marsh-land Sluice to Caldecot Farm, on the west side of Whittlesea Mere. It was to be level for its whole length, which was 31 miles, but it was only partially carried out. It extends 11¼ miles from the upper end of the Eau Brink Cut, and communicates with Popham's Eau and the Sixteen Feet River, which are two of the main drains of the Middle Level.

The main drain, or as it is now called, 'Walker's Cut,' as at first made, in 1847, had a bottom width of 50 feet at its lower end, of 40 feet at its junction with Well Creek, and of 30 feet above Well Creek. The level of the bottom was 5 feet below low water in the Ouse at the outlet, with an upward inclination of 1 inch per mile, as far as Well Creek, where sluices were placed to keep up the water in that river for navigation. The cills of the Well Creek Sluices were laid at the same level as that of the Outlet Sluice, which was placed at the upper end of the Eau Brink Cut, consisting of three openings of 20 feet each; and the cill was placed about 8 feet below the level of low water in the Ouse at that place. In 1848, it was determined to deepen, with a few exceptions, all the main rivers and drains of the Middle Level, —about 110 miles,—from 4 feet to 7 feet, with bottom widths varying from 12 feet to 30 feet; (the exceptions were Well Creek, the Old River Nene through Upwell and Outwell, the Old Bedford River, King's Dyke through Whittlesea, and the course of the Old Nene through Farcet;) to construct an aqueduct under Well Creek; to make new cuts, or junctions between the Sixteen and Forty Feet Rivers, between the Twenty Feet River and Bevill's Leam, and between Bevill's Leam and Conquest and Yaxley Lodes; to make a small catchwater drain between Stilton Brook and Yard's End Dyke; to place locks at Upwell, Horsway, and Ashline, for the purposes of navigation; also to make several internal drains and other district works. In consequence of these works, which were all completed in 1852, the water in the rivers and drains was lowered 6 feet.

The cost of the whole of the works above referred to, including Parliamentary and law expenses and purchase of land, has been £410,000.

In 1857, it was determined to take another step towards the completion of Mr. Walker's original design. This was by deepening Walker's Cut 4 feet, or 1 foot below the outlet cill, with a level bottom for its whole length of 11¼ miles, keeping the bottom width as before, viz., 50 feet at the lower end and diminishing to 40 feet at Well Creek. Up to this point the work was completed last year, and it is now being continued upwards. Each step that has been taken in the improvement of the drainage, since 1842, has been attended with the most satisfactory results,

of which the best proof is, that the money, which is raised by taxation, is collected without difficulty.

The Norfolk Estuary Company have been, for some time past, reclaiming the land from the sea at the mouth of the Ouse, and have cut a new channel, from below Lynn, which has reduced the level of low water in the Eau Brink Cut, and has much improved the drainage of the Middle and South Levels.

ANCHOLME LEVEL.—The next case, by way of illustration, is that of the Ancholme drainage. In 1845, a Paper was read before the Institution, by Sir John Rennie, giving "An account of the Drainage of the Level of Ancholme, Lincolnshire."[1] It is introduced here, as specially bearing upon the subject of "Arterial Drainage and Outfalls," and as demonstrating the good that has resulted from a well-directed and comprehensive system of drainage. The works were many years in progress, arising from various causes, but they have at last been completed.

The level, consisting of about 50,000 acres, extending about 24 miles southward from the Humber, was, from a very early period, the object of attention. From 1290, when Edward I. issued a commission to inquire into its state, and for several successive reigns, commissions were appointed, plans were proposed, and occasionally some works were performed, which rendered partial relief. But from want of attention, the level relapsed into a very bad state, and so matters remained until 1769, when an Act of Parliament was obtained, under which a sluice at Ferraby, where the Ancholme joins the Humber, was made, a lock was constructed, and the river was straightened and improved as far as Bishop's Bridge, a tax being levied upon the land for the purpose of paying for these improvements. Although the outfall cill was placed 8 feet above low-water spring-tides, much benefit resulted from these works. Still the flood water was prevented from getting away, and the drainage was in such a very defective state, that the land was unfit for tillage, and, except in fine seasons, crops of barley, or oats only grew upon the most favoured parts of the level.

Not only had 50,000 acres of low level to be drained, but the water from about 150,000 acres of the high lands bordering on the east and west sides of the level was to be provided for. To prevent the discharge from so great an area descending upon and overflowing the level, catchwater drains were brought into use, for the first time, upon any general enlarged scheme. These catchwater drains diverted and carried off the surplus water, and were the means of supplying the drains in the low lands with water for

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. iv. p. 186.

irrigation and navigation in dry seasons; which is as essential as the drainage in excessive wet seasons. Some of the propositions made in 1801, by the late Mr. Rennie, were carried out, but the others were not executed.

The Paper then states, that Sir John Rennie was called upon, in 1824, in consequence of the works, from insufficient funds, not having been carried out as proposed, of their getting out of repair, and of the insufficiency of the drainage, to make a report, plans, and estimates. The works, including the building of the Ferraby Sluice and Lock, the bridge over them, and the bridges over the main river, are minutely described. The benefits derived from the satisfactory completion of these works are thus enumerated:—"The sure principles of drainage,—catchwater drains for the high-land waters, and improved rivers and drains for the low-land, or fen waters,—have been established, and the whole of the Ancholme Level is now converted into a rich arable district, capable of producing the finest crops of every kind."[1]

Principles of Improving Rivers in Flat Countries.—In the Paper on the Ancholme, as well as in all that has been introduced relative to the fen district, some of the leading principles of the drainage of level areas were noticed, and they have since been carried into execution. They were, first, the formation of catchwater drains for intercepting high-land waters; secondly, the separation, as much as possible, of navigation from drainage, in improving rivers; thirdly, the proper slopes, or inclinations, to which the bottoms of improved rivers, or newly-cut drains, discharging into tideways, should be formed; fourthly, the proper depth at which the cills of outfalls into tideways should be laid; and, fifthly, the formation of overfall weirs and reservoirs for the retention of mud and sand.

First. There seems to be no doubt, that both in level areas, and also where there is considerable fall, catchwater drains are of great utility, and in the latter case, they can be made of great value for irrigation, for water power, and for storage.

Secondly. As to the separation of navigation from drainage, the Author has long been of opinion, that the one is incompatible with the other, each being designed for distinct purposes; and the interest of maintaining the one is frequently inimical to that of the other. But in some of the old rivers, it would involve so great an expense to separate them, that it is preferable to continue them together; in any newly-designed drainages, however, the two may, in most instances, be kept distinct.

Thirdly. In a few counties, the improved rivers, or drains may,

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. iv. p. 199.

in nearly all cases, be made level; for they then serve as reservoirs for the water, during the time the sluices are closed, the water suffers less friction, and as Smeaton states, the whole body of the water is in motion.

Fourthly. The depth at which the cills of outfalls should be placed below low water, has produced some controversy. There can be little doubt, however, that about 2 feet may be adopted. In the Middle Level drainage, as before stated, the outfall sluices into the Ouse have been laid 8 feet below low water. This was probably done in anticipation of a lowering of the Ouse below Lynn, of which it is capable, and which is now being effected by the Norfolk Estuary Company, to the extent of 5 feet, or 6 feet through Vinegar Middle to Lynn Deeps.

Fifthly. This is a provision which may, or may not, be requisite. If the river, or streams convey mud and sand, then such a work would be useful, as it would prevent the drains from becoming choked, as well as admit of their being cleared out in dry weather, without interfering with the action of the drains.

A principle which has not been referred to may be mentioned, as included in the resources open to the Engineer;—where the bottoms of rivers and streams can only be sunk at shallow depths below the land, and those rivers and streams are subject to sudden and short floods, banks may be erected on each side, so as to retain the floods: this is an inexpensive system, as the earth taken out will form the banks.

Another principle is, in some cases, necessarily applied to assist draining;—elevating water from back drains, by machinery, either to the higher level, or for the purpose of discharging them into main drains, which may be on the same level as the internal drains. This principle was carried out, to a great extent, in draining Whittlesea Mere a few years since.

YORKSHIRE.—In many parts of Yorkshire there are large drainage districts, mostly under the jurisdiction of Commissions, having Acts of Parliament enabling them to raise money, execute works, and levy taxes upon the lands. Several of them have done much good, in reclaiming lands which were valueless, in fact morasses and swamps, and bringing them into such a condition as to become fertile and of considerable value.

An estate in Yorkshire, of about 2,250 acres in extent, at Thornton, near Pocklington, is at this time, suffering considerable injury from the want of facility for draining the water from it. The present means consist in discharging the water into a drain which joins a brook called the 'Four Beck Ends,' at about 3½ miles from the Derwent. This brook receives the drainage of two other

streams, which bring water from 40,000 acres of land. The fall in this distance is only 3 feet 6 inches, and the width about 9 feet.

This estate has had 300 acres of the best land, for the last ten, or twelve years, almost always under water, and the remainder more, or less injured. The district was formerly under the jurisdiction of the Howden Court of Sewers, which was instrumental in keeping the watercourses open for the passage of surface water; but in consequence of litigation, it has long since ceased to act.

Many more cases might be mentioned, in which works have been carried out, or are in progress, particularly in connection with the Ouse and the Derwent, showing the advantages that can be derived from combination, on the part of those interested, in improving their estates; thus conferring great national benefits by bringing more land into profitable productiveness, giving employment in the localities, and improving the salubrity of the district in which they are situated.

HAINAULT FOREST.—This forest, (formerly a royal forest,) is situated in the County of Essex, about a mile and a half to the north of the Eastern Counties Railway, between Ilford and Romford. The allotment made to the Crown contains about 2,000 acres; it was disafforested in the year 1853, and all the timber, consisting of oak and hornbeam pollards, was cleared off in the three following years. The land, in its original state, was covered with a thick growth of underwood, as well as of timber, coarse grass, rushes, and weeds, and the greater part of it was a mere swamp. The formation of the ground consists of a level plain, part of it known as Fairlop Plain, lying at the foot of a ridge of land sloping towards the south. Another ridge projects into it from the east, and at the foot of these ridges are valleys, which bring down the water from beyond the limits of the Crown allotment. The soil on the northern and south-eastern sides is generally a strong brown clay; the remainder of the allotment is mixed clay and gravel.

The first operation in the reclamation was that of making the roads and arterial drains. It will be observed, (Plate 3,) that some of the roads and arterial drains are parallel, affording materials for the formation of the roads, and preventing, at the same time, much severance of the land.

The three principal valleys are, first, the Dog Kennel Brook which extends from the southern boundary of the allotment at Little Heath, and runs nearly due north to the northern boundary, where it receives the drainage of the ridge upon which Chigwell Row stands, and branching off at the second road towards the north-east, receives the drainage of that part of the same ridge.

Out of the Dog Kennel Brook, about half a mile from its outlet at Little Heath, the Well Ridden Brook branches off, towards the north-east, and receives the drainage of the land for some distance beyond the boundary of the allotment. A little above where the last brook branches off from the Dog Kennel Brook, and on the opposite side, is a small drain, the Aldborough Hatch Drain, which receives the drainage of the west and north-west parts of the allotment, and the lands north of it. A small portion of land on the west side is drained by a separate outfall. This is the only portion of the water which is not discharged by the Dog Kennel Brook outlet.

In each of these valleys, straight and regular open drains have been formed, proportioned to the quantity of water it was calculated they would have to carry off. Into these open drains all the mains of the pipe drainage, which has been executed over an area of about 2,000 acres, have been carried; as well as the surface water of the allotment and lands adjoining. The water which formerly passed through these valleys, can scarcely be said to have been carried off by streams, as there was little, or no indication of any ditch, or track by which it could be discharged; but it found its way over a great part of the land, where it lay for weeks, destructive both of vegetation and health, till it was mostly carried off by evaporation. It was frequently Midsummer before the land was sufficiently dry to walk upon; consequently, little produce was grown, and the quality was almost worthless.

The length of the Dog Kennel Open Drain in one line, from the south to the north-east, is about $3\frac{1}{2}$ miles; the area drained by it is upwards of 3,000 acres. The Well Ridden Drain, to the north-east, is $1\frac{1}{4}$ mile in length, and receives the drainage of 670 acres. The West Drain is $1\frac{1}{4}$ mile in length, and drains 452 acres.

It was expected, that the water from the high ground surrounding the allotment, and from the large quantity of underground pipes in the allotment, equal to 615 miles in length, would be discharged in large quantities and in very short periods. The following dimensions and slopes were, therefore, given to the drains; the bottom of the Dog Kennel Drain at its outlet, was made 6 feet in width, and from 4 feet to 5 feet deep; the bottom width diminishing gradually to 2 feet at the upper end. The inclinations given to the bottom are shown on the section accompanying the plan, (Plate 3). The natural fall of the valley, at the surface of the land, to the second road, is 1 in 171, and 1 in 125 for some distance above the road. This fall would have been too great, under the circumstances before-stated, and the velocity of the water would have been such as to destroy the sides and bottoms of the drains. Overfalls, built of brick, were, there-

fore, put in the drain, as indicated in the plan and shown on the section. By these means the gradients were reduced from 1 in 171 to 1 in 330 in the lower part, and from 1 in 125 to 1 in 200 in the upper part. These overfalls, which vary from 10 feet to 3 feet in width of opening, and rise from 3 feet to 5 feet, were so constructed, by inserting boards into grooves, as to be capable of being made into dams, for storing water in dry seasons for cattle, or other purposes, and for irrigating the land on both sides. The Well Ridden Drain was the only other drain that was treated in this manner; its gradient was reduced from 1 in 147 to 1 in 200, by two overfalls.

The dotted lines on the map, (Plate 3,) show the pipe drains, the smaller pipes leading into larger, or main pipes, which discharge into the open drains at the points shown. The minor drains accurately describe the contour profile of the land, their direction being always that of the greatest fall.

At one of the farm buildings a tank was constructed to supply the premises with water, and there is a feeder leading to it, branching out of the Dog Kennel Drain, where a dam is placed to regulate the quantity of water.

The system adopted in thoroughly draining this large district was, to have as few open drains as possible; and mains with large pipes were extensively used, considerably increasing, of course, the first cost. But the area of land thereby gained for profitable cultivation was increased in proportion, and the labour of tillage largely reduced; independent of which it is found, that agriculturists neglect the mouths of under-drains, if they are numerous. It is, consequently, good economy to have as few outlets as possible.

The result of the arterial drainage in connection with the underground drainage has been, to carry off all the rainfall with the greatest facility, and in no case have any of the open drains overflowed, but the water has all been confined within the banks.

This forest, from having been from time immemorial almost a waste and useless, has now become a valuable farm, and what was formerly a refuge for thieves and poachers, now affords the means of profitable employment to many persons.

Indian Rivers.—The Paper having thus far treated of works of drainage executed and proposed in this country, a reference to the systems of dealing with rivers in India and in Northern Italy may prove interesting.

The Report by Captain Baird Smith, R.E., to the Court of Directors of the East India Company, in 1856, gives an interesting and instructive description of the manner in which the

large rivers in the Madras Presidency, the Cauvery, the Coleroon, the Kistnah, and the Godavery, are brought under control, and adapted to the purposes of irrigating immense tracts of country. These rivers drain enormous areas, their lengths being from 400 miles to 600 miles, and having drainage areas of from 20,000 to 30,000 square miles. They run upon the crest of ridges, through the deltas near the outfall into the sea, which have been raised by the continual deposit of gravel and other materials brought down from the upper countries. At the head of these deltas, weirs, or dams are erected across the river, which, in the case of the Kistnah, is 2 miles, or 3 miles wide; and other training and protecting works are constructed along their sides, to confine the waters to their channels. This system is adopted at every suitable spot on each river. These dams are provided with under-sluices, or escapes, as they are called, to let off extreme floods, or clear off deposited material. At these dams the proper works, such as sluices, escapes, &c., for conducting the water to the irrigation channels, are constructed. The volume of water which flows down these rivers during times of flood is enormous; and were it not for the substantial and comprehensive character of the works, they would be destroyed; occasionally, they do suffer great injury. The immense quantity of water that is required to irrigate the sugar, rice, and other lands, makes it necessary to provide extensive works. Many of these works are of great age, and several are, at the present time, in course of construction. The Government provides the means for carrying them out, and they are all under the management of Officers of the Indian Engineers. The return for the outlay arises from an increased quantity of land being brought into cultivation, and that of an improved description, which is taxed in proportion.

Perhaps the most extraordinary works connected with irrigation in the Madras Presidency, are the tanks. They are more properly applicable to the subject of arterial drainage, than that of irrigation, connected with rivers, as they assimilate to the English system of storing water, and, as suggested in this Paper, form good examples of a mode of regulating the water in English rivers, under the altered circumstances which are now taking place. There are forty-three thousand of these tanks kept in repair, and ten thousand others in the Madras Presidency alone; many of them being of considerable magnitude. According to Captain Baird Smith, the united length of the embankments of these tanks approaches to 30,000 miles; and they comprise three hundred thousand works of masonry in sluices, waste weirs, &c. The lands irrigated by these tanks are estimated to produce £1,500,000 sterling annually to the Government, and they are supposed to have cost £15,000,000 sterling.

The largest tank at present in repair, as a specimen of many, is that of the Veeranum Tank, which has 12 miles of embankments and 35 square miles of area, and is of very ancient date. It now yields the Government £11,450 annually.

Although the introduction of the irrigation works of India into this Paper is rather a digression from the subject of arterial drainage, the Author has briefly noticed them, partly as highly interesting to Engineers, illustrating the manner of dealing with large rivers and bodies of water, and partly as the works may be applicable to drainage operations, as well as to irrigation, although the one system is quite the reverse of the other. But as works for irrigation, they are totally unsuited to any part of this country, being far too extensive. Nevertheless, the Author would propose, where practicable, to connect arterial drainage, especially in rapidly-inclined countries, with tanks, or reservoirs, since they may become most useful in many ways, as aids to agriculture, or the supply of towns.

Italian Rivers.—Paul Frisi, who was professor of mathematics at Milan, published an excellent treatise, about the year 1760, on rivers and torrents, which was confined chiefly to the rivers in Italy. About that period much controversy was carried on, as to the proper method of regulating the Rivers Po, Sammoggia, Reno, Savena, Idice, and Sillaro, many of which, except the Po, discharged their waters into the Plains of Lombardy, and were conveyed to the sea by the River Primaro. Several attempts were made to bring all these rivers into one channel, the Benedictine Canal, and so conduct them into the Primaro. Frisi discusses fully, and with much ingenuity and knowledge, the circumstances connected with these torrent rivers, and he gives valuable information, as to the materials brought down by them, as well as to the natural formation of the higher beds of rivers, and of the rectification and formation of river beds, the velocities of single rivers and artificial canals, and of rivers united and divided, the slopes, or velocities of rivers, and the distribution of the slopes on rivers which convey mud and sand. But the chief information derived from a perusal of his work, relates to the regulation of rivers which bring down from the Apennines, both on the east and the west sides, bodies of gravel which fill up their beds, and require a particular treatment, according to the circumstances of the several cases. The alterations in the course of the River Po, for instance, have been very extensive, caused, principally, by the tributary rivers bringing down gravel and other matters, which were deposited in its course, and diverted it into an entirely different channel.

Many of the most eminent mathematicians of the time were

engaged in devising plans for diverting the rivers from the valleys of the Sammartina, of the Arno, from the Vale of Chiana, and the Plains of Leghorn, and of Pisa. All the works that were undertaken, were for the improvement of the drainage and outfall of very large rivers, subject to sudden floods bringing down every species of obstruction and detriment, so as to control them and give them a proper action.

The want experienced in this country of arterial drainage arising from the introduction of pipe drainage, and the greater attention paid by those who have the management of land, in clearing the uplands of water, has not been as yet felt in many countries, such as Northern Italy; so that there are few, if any, examples of the descriptions of works in those countries, which this Paper more directly treats of and advocates.

The great hydraulic works of Northern Italy all relate to irrigation and navigation, and perhaps no other country in the world possesses such a large and valuable collection of literature on these subjects as is to be found at Milan. The canals of Martesana, the Naviglio Grande, and some others, besides serving the purposes of navigation, are also used as channels for irrigation. The great hydraulic works are principally devoted to irrigation, which, as a system, has been established from a very remote period, and has been carried out to an enormous extent. The Governments of the several kingdoms of Northern Italy are the owners, as they were, originally, the undertakers of, nearly all the largest irrigation channels, and private families are owners of, or have vested rights in, many of them. Strict, but equitable laws and regulations are laid down, for the use of the water taken out of these channels by the occupiers of land adjoining, for which they pay a tax. The mode of measurement of the water so distributed, is conducted on a different system in every kingdom.

A large number of Engineers find employment upon these works of irrigation, in executing them, keeping them in repair, advising as to the proper modes of irrigation, under the various circumstances that arise, and settling disputes; and they are thus, in numerous ways, connected with a system spread over so vast an area of country, in such a complicated, entangled network of drains.

Interesting as this question is, and one which may be studied with great profit, it does not bear upon the present subject, except as before remarked, in the case of the Indian rivers, so far as arterial drainage may be made to supply the means of irrigation to a great extent.

In upland, or internal rivers and streams, such as are referred to in the last few cases, the leading principles which should be the guide in improving them are: first, the straightening their

channels from the sources to the outfall; secondly, the making them of the proper widths requisite to take in all the flood waters, having regard to the inclinations; thirdly, the formation of shallow, rather than deep drains, in nearly all kinds of soils; fourthly, the regulating, or adjusting the inclinations of the bottoms, so that the velocity of the water may be checked, to prevent the erosion of the sides and bottoms, and the removal of the gravel, sand, and mud to the lower levels; and fifthly, the providing the means of storing up the waters in reservoirs, or tanks apart from drainage, at convenient points, for agricultural and industrial purposes, such as supplying cattle in dry seasons, for irrigation, for small water wheels, and for supplying towns, or districts with water.

The system of banks on each side of shallow drains, may be advantageous in localities in which sudden floods occasionally occur, so as to save excavation and waste of land, because these banks, and the spaces between them and the rivers, are available for pasture lands, if the former are properly formed.

COMMISSIONERS OF SEWERS.—It appeared to the Author, that the Commissioners of Sewers, who are acting in every part of the country, having jurisdiction on the borders of the sea, or tidal rivers, ought not to be passed over without some notice, in consequence of the antiquity of their constitution, the position which they hold in many districts, and of their connection with the objects of this Paper.

The Commissioners of Sewers were first instituted in the reign of Henry VI., for the purpose of repairing sea-banks only. But in the reign of Henry VIII., (23 Henry VIII., cap. 5,) they were better organised and invested with fuller powers, and may be said from that time to have been enabled to act and to be of some service. The law was afterwards amended in Elizabeth's reign, (13 Elizabeth,) and now they are acting under the 3 and 4 Will. IV., cap. 22. Their duties are to repair sea, or river banks, and to keep the main drains and outfalls of level districts in repair, and clear them for the passage of water. This is done by jury presentments, compelling the owners and occupiers of adjacent lands to perform all necessary repairs and works.

The objects for which they were constituted are of great importance, and the duties are generally well performed, but their powers are not extensive enough to meet the exigencies of the improved state of society and the management of land, which makes them, as a body, less effective and useful than they might be. The machinery for taxing is unsatisfactory, requiring for new works, three-fourths of the owners and occupiers to consent to the work being undertaken, and the same proportion to agree to the tax. The services of the Commissioners, whose powers are renewed

periodically by the Lord Chancellor, are gratuitous, and it is only a matter of surprise, that any one can be found to act, except when they are directly interested in the lands to be protected and drained. In the case of ordinary repairs, or works under a certain amount, the Commissioners can order their officers to perform them, or compel the owners to do so. The Author has lately executed a work, which the owners of the lands and river were compelled to undertake at a large cost, under one of the Courts of Commissioners.

The whole constitution of these commissions requires, in the Author's opinion, to be remodelled, and large and more effective powers must be given to them, in the event of any fresh legislative measure being carried upon these subjects.

There are many more instances of the improvement of rivers, both proposed and executed, than those which have been noticed in this Paper. The system pursued in Holland has not been touched upon. This in itself would be sufficient for a Paper; but the length to which this communication has already extended, precludes a more complete and detailed account. Some of the cases could only be generally described, and they must be merely taken as illustrations, presented in the hope of promoting a more universal improvement, and that the subject may attract the attention its importance demands, and lead to more perfect and liberal legislation.

The Paper is illustrated by a series of diagrams, from which Plates 2 and 3 have been compiled.

[Mr. LOCKE, M.P.

Mr. Locke, M.P.,—President,—said, that whether the views of the Author, relative to the advisability of legislative interference in the drainage of lands passing through numerous properties, were generally concurred in, or not, all must agree, that there were instances in which obstinate landowners would not allow their land to be improved, notwithstanding the advantages which they might derive from it; whilst, on the other hand, there were men of progress, who were desirous of carrying out these improvements, and willing to pay their quota of the expense. There were great difficulties in dealing with a question of this kind; but it had been treated with fairness in the Paper, especially with regard to compelling landowners to carry out improvements against their will. The Paper also contained a history of several important operations, projected and carried out, showing the progress of arterial drainage, which must be interesting to every one who had given any attention to the subject.

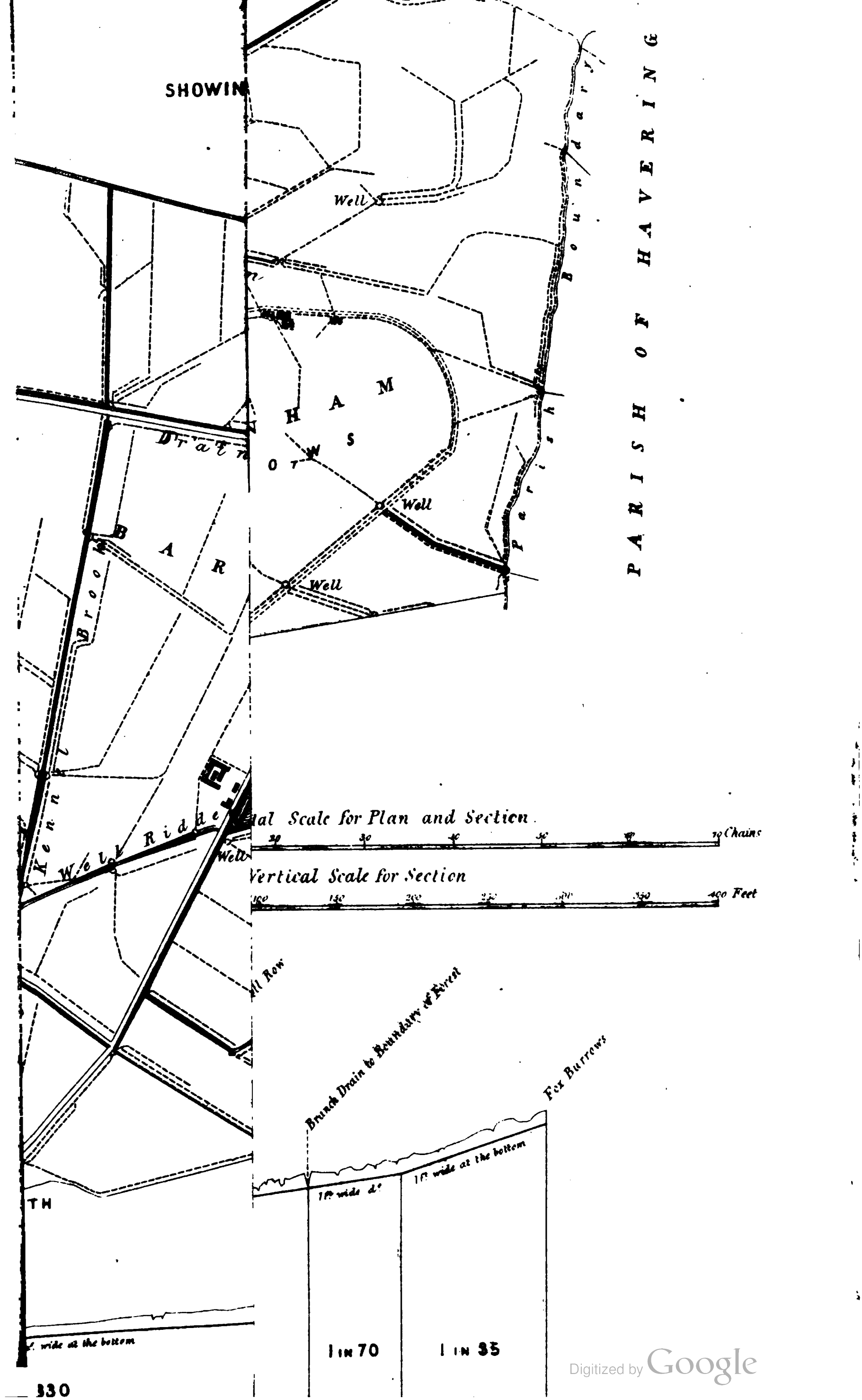
Mr. Bailey Denton had been engaged, for several years past, in operations of under-drainage, by which he had become aware of the want of some comprehensive measure for the control of arterial drains and outfalls; or rather, some central commission, with powers to facilitate the drainage of land. One point of importance, which had been alluded to in the Paper, was the difficulty experienced by landowners in finding an outlet for injurious water, owing to the opposition of parties who held interposing lands. It was a fact, that at this time, there were no tangible means of compelling landowners to allow the water from another estate to pass through their property, however important the improvement sought to be effected, and however small the value of the interposing land. He was, at the present moment, draining an estate belonging to Lord Palmerston; and the lower part of that estate must remain a comparative swamp, if the owner of the property lying still lower, would not consent to an outlet through it. He alluded to the case of Lord Palmerston to show, that the Premier of England was in the same position as the smallest freeholder, and in confirmation of the necessity of affording some easy and cheap means of redress. Another inconvenience very generally experienced, was the absence of any law by which a common watercourse, however tortuous, or deficient in capacity, could be straightened, or deepened. An Act, called Lord Lincoln's Act, enabled a person aggrieved by the stoppage of an existing watercourse to make a complaint before a magistrate, who had power to order the party to clear, or scour out, that watercourse; but there was no power to order it to be deepened, or otherwise improved. Much had been said, of late years, about deep drainage; and he could speak from experience, of the enhanced value of agricultural property from that operation. Now

PLATE 2, VOL. XIX.

Plate presente

of Proceedings, Institution of Civil Engine

I. BROS LITHRS CASTLE ST. HOLBORN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Boundary
Parish
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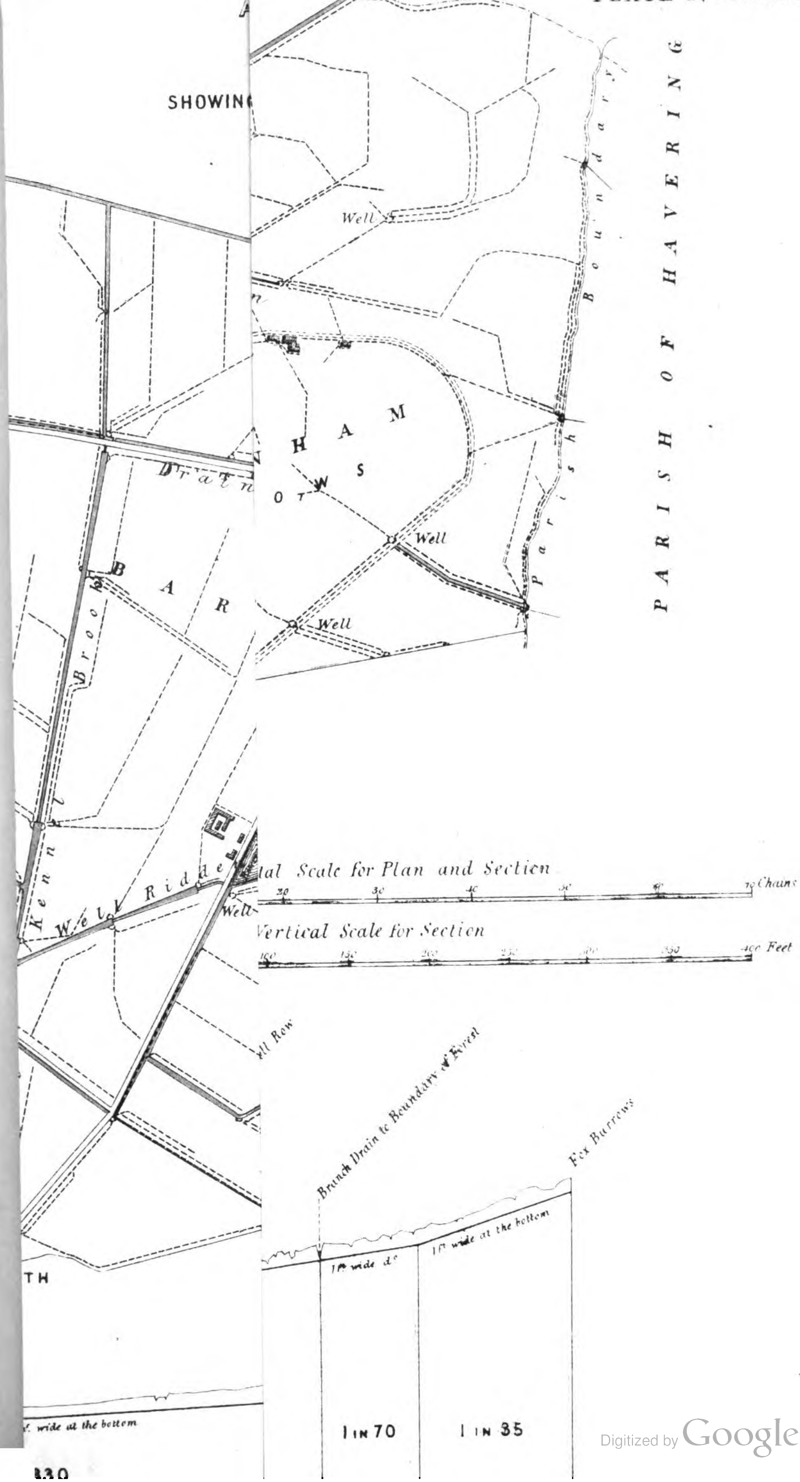
HAM
OWS
Drain
BAR
Kennel Brook
Well
Well Row
al Scale for Plan and Section
10 Chains
Vertical Scale for Section
400 Feet
Branch Drain to Boundary of Forest
Fox Burrows
1ft wide d°
1ft wide at the bottom
wide at the bottom
1 in 70
1 in 35
TH
330


SHOWING
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Vertical Scale for Section
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Branch Drain to Boundary of Forest
Fox Burrows
1ft wide at the bottom
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1 IN 70
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wide at the bottom

scarcity of water for cattle, and in which the inhabitants of the villages were left almost without that common necessary of life.

Another important matter was, the necessity of regulating the discharge of the refuse of towns into the arterial streams. He considered, that any commission dealing with arterial drainage, should embrace that topic. He could speak from observation, that many streams which had been used profitably for household purposes, and for the supply of towns, were now unfit for those purposes. There was another view of this part of the question, which had a commercial bearing on the value of rural property; the depreciation in the beauty of the rivers. Streams, which were formerly clear and pleasing in the landscape, were so no longer; and he considered that question not entirely devoid of interest and importance. The way he proposed to bring about this great desideratum of a controlling commission was, that some commission of inquiry should be appointed by Government to look into these minor matters, as well as the more important one of main outfalls. He thought the minor matters to which he had alluded would be considered, in the eyes of agriculturists, as more important and urgent, and therefore, more likely to meet with support in the Legislature, than the large and comprehensive measure of dealing with millstreams, involving the opposition of millowners.

Mr. JOHN CLUTTON mentioned several instances, in which efforts to carry out improvements, and to increase the fertility of land, had been frustrated. Some years ago, a considerable district in the vicinity of Maldon, in the County of Surrey, was drained by Mr. Easton. When Mr. Clutton undertook the management of the estate, he found, that one of the bridges, which had been lowered, had been stopped up again, by order of the county surveyor. That obstruction had been placed there by the surveyor, simply on account of some little disagreement with the owners of adjoining land about charges. The whole of the invert was filled up to the original level with concrete; thereby stopping all the drainage water of the district. There was no legal power to compel the removal of the obstruction, and it was only effected by the payment of a sum of money, to enable the county magistrates to undo what they had wrongfully done. A large sum had been expended in the improvement of the district; but the arch of the bridge being filled up with concrete, the outlay was rendered useless, the produce of the land was diminished, and the health of the resident population was injuriously affected. After the impediment had remained there for about fifteen years, the concrete had been removed; and in the year 1858, other parties in the district brought a Bill into Parliament for further improvements. This Bill was strenuously opposed by one landowner, who used every effort

to prevent the drainage being carried through one of his fields; and thus the possible improvements of the whole district were prevented. Surely there ought to be some general measure, which should frustrate trivial opposition to large plans of improvement, such as he had alluded to. The parties to whom he referred, were at considerable expense to bring in the Bill, but their efforts were destroyed by the opposition, in fact, of a single person.

He happened to be attached to the Commission in Ireland, to which the Author had alluded. He thought the state of the streams in this country very inferior to their condition in Ireland, where they had been improved under the pressure of the famine. Arterial drainage was there carried out on a large scale; and although much of the work was costly, yet great improvements had been effected. The landowners complained of the cost, but the land was improved to a large extent. A tax of one shilling was objected to, although the land had been improved to ten times that amount. He thought the value of drainage, especially of arterial drainage, was not so fully appreciated as it ought to be. He knew land near the Thames, which might be made worth three times its present value, if the drainage was properly carried out. There were innumerable obstructions to drainage, which, in the existing state of the law, there was no power to remove. There were cases in which mills not worth £50 a year, were damaging large districts to the extent of hundreds of pounds. It appeared to him unaccountable, that some general and comprehensive measure had been so long delayed; but with the aid of the great practical body of Engineers, represented by the Institution, he had no doubt it would, eventually, be obtained.

Mr. Simpson, (Past-President,) said, this subject had occupied a great deal of his attention, and, in his younger days, a portion of his professional income was derived from surveys and plans for draining and improving landed estates. The same obstructions existed then as at the present time, through the opposition of other landowners. More than forty years ago, he had found difficulties in obtaining outlets for land drainages, and they had increased, from year to year, owing to the circumstance, that the landowners in the higher parts required, in carrying out their modern plans of drainage, to let the water down through the estates in the low lands. He had been for many years acquainted with the valley of the Baveley Brook, to which allusion had been made, and he could state that, whereas formerly, it required three-quarters of an inch of rainfall to flood that valley, now only half an inch sufficed; some of the higher lands at Merton, Maldon, and in the direction of Sutton having been under-drained with tiles and pipes. Many similar cases might be mentioned. The fact was, that the drainage of the upper lands threw the water more rapidly into the small brooks

and streams in the lower lands; and grass lands, which had formerly been seldom flooded, were now, to their great detriment, frequently visited with floods, and kept in a swampy state. This was not only the case in Surrey and in Middlesex, but in many other counties of England, and he had long thought it a great evil. At present there was no effectual remedy; but he hoped the magnitude of the mischief would shortly lead to some general legislative measure, enabling the landowners to combine, not only to carry out a proper system of drainage, but to maintain it when once executed; for much of the evil complained of arose from the existing drainages not being properly maintained, causing injury to the lower lands. He had known cases in which, after £8,000, or £10,000 had been expended, the drains were not maintained after seven years; because the lands, in some cases, belonged to minors, or were in the hands of trustees, or under the control of guardians of incapacitated persons, so that there being no one to contribute to the expense, the drainages went out of repair; and under such circumstances, as much injury was done to the lower lands as if there had been no drainage at all.

The project for the drainage of the low lands in the neighbourhood of Wareham was one in which the late Lord Eldon took great interest. Walking over the estate one day with his Lordship, wheat was observed growing upon land 4 feet above the point of drainage of the salt water. The tenant was persuaded to improve the drainage, by which he was enabled to sow with wheat 20 acres of land, that, previously, was not worth five shillings per acre, whereas now it was worth, at least, two pounds per acre. If a thorough system of drainage could be introduced there, 2,200 acres of land would be rendered very valuable. Some of the landowners, however, objected to drain, notwithstanding it could be done with a natural outfall of 12 feet. Instead of this, they suffered the lands to be flooded during three, or four months in the year, which rendered it comparatively unproductive. In the lower lands, near Wareham, where great benefit would result from such a system of drainage, nothing was done, and one gentleman had stated, at a public meeting, that if the work would cost only one shilling per acre, he would not do it; the fact being, that he could not command the money, and he was, therefore, determined not to consent to the measure.

Sir John Rennie, (Past-President,) fully agreed with the opening remarks in the Paper, as to the difficulties that were experienced in carrying out measures for arterial drainage, without specific Acts of Parliament empowering the construction of particular works. Each case differed from every other, and required special provision to enable a proper plan of drainage to be effected: and he thought, there would be great difficulty in carrying into

execution, any general rule which might be laid down. In fact, in this country, where the rights of property were so complicated, he was afraid, that any general measure, to be effectual, would be so injurious by its interference with those rights, that he doubted the propriety of attempting to establish such extensive changes as would, necessarily, be involved.

The Author had made especial mention of the drainage of the levels of Cambridgeshire, Lincolnshire, and other places in England. This was a subject which required considerable research, in order to ascertain the varying state of the drainage of those districts at different periods, the works that had been carried out, and the results produced. Without entering into minute particulars, he would, as briefly as possible, mention a few facts relative to the history of the drainage of the fens, in which, he might add, he had been rather extensively engaged. The Romans were said to have greatly contributed to the improvement of the drainage of these districts, and several of their works, such as the Caerdike, the Podike, the Causeways, &c., still remained as specimens of their skill. As the shores, or sea line of the Great Wash formerly extended much further inland than at present, it was probable, that their labours were, to a considerable extent, successful. From their departure from Great Britain, A. D. 422, until the reign of Stephen, A. D. 1060, the Roman works were abandoned, and no others were executed, so that the fens were little better than a vast lake, or swamp, except the higher parts, such as Ely, March, Ramsey, Whittlesea, Thorney, and Crowland, which formed so many islands rising out of the waste of waters, accessible only by boats, or by causeways connecting them with the high lands. But at a much later period, considerable results had, no doubt, been obtained by the improvement of the drainage in the Middle Level. That district, which contained about 150,000 acres, lay between the Nene and the Ouse, and for centuries back, the drainage had been in a very bad state. Now with regard to the period when the Nene and the Great Ouse discharged their united waters into the Great Wash, at the town of Wisbeach, which was situated about the centre of the Wash. In former ages, that outfall was said to have been good; yet in the course of time, the alluvial matter brought down from the interior, as well as the sand driven in from the Great Wash by the easterly winds, obstructed, or blocked up the mouths of the Great Ouse and the Nene, to such an extent, that they could scarcely discharge their waters with any effect. In consequence of this obstruction, the Great Ouse was driven back and diverted from its course, and approached within about 3 miles of the Little Ouse, at a place called Littleport Chair. The whole country through which the Great Ouse passed, was then flooded to such a degree, that the inhabitants of the

district were placed in the greatest difficulty, and not knowing how to get rid of the water by the old outfall, they made a cut about 3 miles long, from Littleport Chair to the Little Ouse, at Rebeck; thus the whole, or greater portion of the waters of the Great Ouse, the Cam, the Little Ouse, and their tributaries were discharged into the Great Wash, at Lynn. There was, in consequence, a great accession of water at this new outfall, which materially improved it. This took place about the year 1292. The north portion of the Middle Level, the North Level, and South Holland suffered in the same proportion, and were so overwhelmed with water, that the highest parts only were called summer land; that is, they were only grazed and cultivated for a few months during the year, and for the remainder, they, as well as the other lands, were more, or less, under water.

It was not until about the time of Charles I., that this subject again attracted serious attention, when very protracted discussions took place as to the best means of remedying the then deplorable state of things. A commission was accordingly appointed, and a contract was made in 1630 with Francis, Earl of Bedford, to drain the fens, for which he was to receive 95,000 acres as a recompense. The Earl employed Sir Cornelius Vermuyden, a Dutchman who had settled on Hatfield Chase, to make plans for the intended work, which was said to have been completed in fourteen years; but it afterwards proved defective, and the contract was annulled. Charles I., who was fond of speculation, then determined to undertake the work himself, employing Vermuyden as his Engineer, but the Civil War intervening, the contract was never carried into effect. The drainage was subsequently completed in 1652, according to Vermuyden's plan, by William, Earl of Bedford, and his associates. By this plan, the channel of the Great Ouse was shortened 10 miles, by a new cut, about 21 miles long, from Earith to Denver, where a sluice was placed across the united channels of the Great and Little Ouse, the Grant, or Cam, and the Stoke, Brandon, and Mildenhall Rivers, so that all the floods of the Great Ouse above Earith were discharged through this new channel, without passing through the South Level. Several other interior drains, sluices, &c., were also executed in connection with the above works. After much discussion, Vermuyden's plan was carried into effect, and the level of the water was considerably lowered; and 95,000 acres of land were awarded to William, Earl of Bedford, and the parties who, jointly with him, had incurred the expense of the drainage. After some years, it was proved, that the level was not well drained, and that Lynn Harbour was injured. Then followed endless discussion and litigation. At last, in 1713, Denver Sluice was undermined and blown up by the waters, and the tide, in consequence, was again admitted to its old receptacles,

whereby Lynn Harbour was improved. In 1750, in spite of strong opposition, Denver Sluice was rebuilt. Some partial improvement was then effected in the South Level; but the drainage still remained very imperfect. The superior velocity of the great mass of water coming from the straight New River, greatly retarded, or over-rode the waters discharged through Denver Sluice; but if the Old River had been properly embanked and improved, and had been connected with a judicious system of interior works, the drainage navigation and outfall would have been far better improved and maintained without the sluice at Denver, which was improperly applied there. It would be tedious to go into details of the various plans subsequently proposed by the most able Engineers of the respective periods, including Westerdyke, Kinderley, Armstrong, Labelye, Golborne, Watté, Elstobb, Smeaton, Mylne, Page, Huddart, &c. Their plans were fully discussed; but nothing further of consequence was executed. The South Level, including the high lands around it, containing 173,000 acres, and the Middle Level, containing about 150,000 acres, had been separated from the North Level, of which the area was about 50,000 acres. About the year 1724, Bridgeman, who was evidently possessed of considerable ability, proposed as the only remedy for the drainage of the Middle and South Levels, to make a cut from a place called Eau Brink, about a mile below German's Bridge, to Lynn; by which means, he argued, the river would be brought into better working condition and the water in it lowered by about 5 feet. It required many years of further discussion, before it was finally considered absolutely necessary to carry out that plan, in order to improve the drainage; and it was not till 1795, that the first Act was obtained. At that period, the cost of the cut was estimated at £39,985; but in consequence of the numerous investigations and the litigation which subsequently occurred, (notwithstanding that the Act was obtained,) the whole of the money, which had been raised by local taxation, was expended before the work could even be begun. No one would submit to fresh taxation, and the Act, consequently, was not, at that time, carried into effect.

In 1809, the Bedford Level Corporation applied to the Father of Sir John Rennie, to make a complete examination of the South and Middle Levels, and to report upon them. In 1810, he made a Report, in which he entered fully into the cause of the evils, viz., the defective state of the outfalls and channels of the rivers, and the bad system of internal drainage. He proposed, as a remedy, that the Eau Brink Cut should be made according to Captain Huddart's award, that the other bend on the Ouse above Magdalen Bridge should also be cut off, that an entire new cut should be made for the Ouse from Denver Sluice to Earith, that the other

rivers should be improved, and that either a new improved and enlarged sluice should be constructed instead of Old Denver Sluice, or that the tide should be admitted into the old river above, without the sluice. With regard to the interior works, he proposed, that there should be a complete system of arterial and subsidiary drains connected with the Ouse at the Eau Brink Cut, and that capacious catchwater drains should be made between the Nene near Peterborough, and the Ouse at Earith, along the base of the high lands between these places; also that another catchwater drain should be made from the Ouse at Earith, thence skirting the base of the high lands in the South Level, and entering the Ouse below Denver Sluice. By these means, the whole of the high-land water coming from the higher level, would have been intercepted and discharged into the upper part of the Rivers Ouse and Nene, where there was ample fall; and thus the water from the low lands, having less fall, would have been discharged at the lower part of the river, at the head of the Eau Brink Cut, without being interrupted by the high-land waters. This plan for the drainage of about 300,000 acres was estimated to cost £1,300,000. At that time it was, however, unfortunately considered too great an undertaking, although, considering the amount of land to be drained, the cost was very moderate, and would have been amply repaid; no steps, therefore, were taken for several years. At last, in 1818, as the drainage was still in a very defective state, it was resolved, in the first instance, to execute the Eau Brink Cut. A new Act of Parliament was accordingly obtained, with ample powers to raise the necessary funds, and in 1821, the cut was completed according to Huddart's award, together with numerous interior works required by the Act of 1793, which could not be altered, although Mr. Rennie was desirous, that the money should be expended more profitably in carrying into effect other works, according to his plan. By the completion of the Eau Brink Cut, the low-water line was lowered about 5 feet at the upper end of the cut, which produced a corresponding improvement in the general drainage. Although only a small portion of Mr. Rennie's plan had been carried out, sufficient advantage was supposed to have been obtained, and it was not until 1844, that the proprietors of the Middle Level, finding they had not received the benefits which they had anticipated, obtained an Act of Parliament to complete their interior drainage. They adopted that portion of Mr. Rennie's plan which proposed to make a main drain from Whittlesea Mere to the head of the Eau Brink Cut, although in rather a different line, but they omitted a most material part of his plan, his catchwater and subsidiary drains. The plan was executed, although it was evident, that it would not be sufficient to drain Whittlesea Mere and the adjacent low lands, without steam and other works,

for this district was the lowest and the furthest from the Eau Brink Cut, being distant from it about 30 miles. It should be observed, that when a general plan could not be adopted, and it was only required to drain small detached districts, Mr. Rennie had previously, in the year 1789, proposed to drain Swaffham and Bottisham Fens, amounting to about 5,000 acres, in the South Level, by steam power, which he afterwards accomplished in 1821. Had the catchwater drains between the Nene and the Ouse been adopted, the high-land water would have been discharged about 30 miles above, and the low-land waters would have been well carried off to sea, before the high-land waters had joined them. When the work was completed, it was found, that a good drainage could not be effected by it, until some further works were undertaken, such as steam power for the district adjacent to Whittlesea Mere, and an improvement in the outfall below Lynn, which was proposed by Sir John Rennie in 1839, and for which an Act of Parliament was obtained in 1846. In 1849, the late Mr. Robert Stephenson and Sir John Rennie were called upon to arrange what was really required, a complete and comprehensive plan for the improvement of the outfall below Lynn: the result was a similar plan to that of 1846, and in 1850, an Act of Parliament was obtained to carry it into effect. The Eau Brink Commissioners for the general drainage of the fens and the Corporation of Lynn were so convinced of its importance, that they agreed to contribute towards the expense £60,000 each, or £120,000. This plan was, accordingly, carried into effect under the direction of Mr. Robert Stephenson and Sir John Rennie, and the result had fully justified the anticipations that had been formed. A further lowering of the low-water mark, to the extent of about 6 feet, had been gained, which, added to the former gain of 7 feet, made a total of 13 feet. Seven feet had been gained by the Eau Brink Cut at the upper end, viz., 5 feet by the original cut according to Huddart's award, and 2 feet by the subsequent enlargement of that cut by Mr. Telford and Sir John Rennie. Six feet had been gained at the lower end in Lynn Harbour, by the Norfolk Estuary Cut. It should be observed, however, that between the periods of making the Eau Brink Cut and the Norfolk Estuary Cut, the low-water mark had risen nearly 2 feet at the lower end of the Eau Brink Cut, by the accumulation of sand in the outfall below Lynn, so that the total fall gained at the upper end of the Eau Brink Cut might be estimated, at present, at about 9 feet; but in proportion as the inclination of the current above adjusted itself to the fall gained below, a further lowering of about 2 feet might be expected, at the upper end of the Eau Brink Cut, thus making a total gain of about 11 feet, or nearly the same as had been gained by the Nene Outfall Cut. These great works, there-

fore, had completely effected the drainage of about 500,000 acres of land, besides greatly improving the River Ouse and the harbour of Lynn.

The great object, in works of this class, was to keep the rivers and their outfalls in as perfect order as possible; and as the channel of a river could only be maintained in proportion to the quantity of water passing through it, it was necessary to bring as much water into the channel, as could be discharged within a given time. By means of Mr. Rennie's catchwater system of drainage, which he applied in 1806, with the greatest success, to the drainage of 75,000 acres of very low lands in the neighbourhood of Boston, but which had been unfortunately omitted in the Bedford Level, the high-land water would have been discharged about 30 miles above the point of discharge of the low-land water into the Eau Brink Cut: thus all the upland water would have passed through the channel of the river, which would have materially contributed to keep it open, and the further advantage of a supply of fresh water from the higher level would have been obtained for the use of the district, during the dry season of summer. This was an important part of the question, because in dry seasons, not only the lands, but the inhabitants of the fens, together with their live stock, suffered considerably from the scarcity of water. In draining particular districts, therefore, attention must be directed not merely to getting rid of the water, but rather to the means of obtaining perfect control over it, so that the proper quantity might be retained, or discharged, as each individual case might require. He believed, that the time would come when drainage would, in many cases, be combined with irrigation and the means of storing and providing water during seasons of scarcity.

The North Level was drained by the Nene, or Wisbeach Outfall, which had greatly suffered from being deprived of the waters of the Great Ouse. In the reign of Henry VIII., Bishop Morton, a distinguished prelate, having a large interest in the district, consulted the best authorities of the day, and it was finally decided to make a new straight cut for the Nene, from just below Peterborough to near Wisbeach, by which the old channel of the river would be shortened about 7 miles. This cut was made and was called Morton's Leam, or Cut, under which name it existed at the present day. It was beneficial, so far as it went, but it bore no proportion to the magnitude of the obstructions in the outfall below Wisbeach, which amounted almost to a complete stoppage of the navigation and drainage. It became necessary, therefore, to discharge a considerable portion of the waters into the outfall below Wisbeach, by the Old Shire Drain which discharged its waters into the Great Wash about 5 miles below Wisbeach; and Kinderley, a well-known Engineer of the day, was consulted. He

at once saw, that the great obstacles to improvement were below Wisbeach, and in order to remove them, he proposed, that a new short straight cut should be made about 4 miles below Wisbeach, just above the outfall of the Old Shire Drain. This work, of which a portion still existed bearing Kinderley's name, was, notwithstanding great opposition on the part of the Corporation of Wisbeach, completed in 1773, and was attended with great beneficial results. Various Reports upon the improvement of the interior drainage were subsequently made by Smeaton and other able Engineers, but they were not acted upon. In 1809, 1813, and 1814, Mr. Rennie made three Reports; one for the improvement of the Nene from Peterborough to the sea at Crabhole, 13 miles below Wisbeach, and the other two for the drainage of the low lands comprised within the North Level, South Holland, and the adjacent districts: still nothing was effected. In the year 1826, Mr. Telford and Sir John Rennie were consulted; they recommended, that in the first instance, that portion of Mr. Rennie's plan for the improvement of the outfall below Wisbeach to Crabhole, should be carried out: an Act of Parliament was accordingly obtained for that purpose, and this great work, called the Nene Outfall, was placed under their joint direction; it was completed in 1830, with very beneficial results. The low-water line was lowered 10 feet 6 inches, which afforded an opportunity of giving a complete drainage to the whole of the above districts, and effected an important improvement in the navigation to Wisbeach. Mr. Telford and Sir John Rennie subsequently proposed to improve the Nene up to Peterborough, upon a plan similar to that of Mr. Rennie, by a cut avoiding Wisbeach, and converting the old channel passing through it into a capacious wet dock connected with the New River, which would have been a great advantage to both; but nothing further was done at the time. Mr. Telford, however, executed a plan for the improvement of the interior drainage of the North Level, similar, in some respects, to that of Mr. Rennie, but as he did not carry the outfall low enough, subsequent works were necessary. In 1836, and again in 1840, Sir John Rennie proposed, that the upper part of the river from the Nene Outfall Cut to Goldicut Staunch, or Lock, about a mile above Peterborough Bridge, should be improved, avoiding Wisbeach by a direct cut to the river, and converting the old channel through the town, into a wet dock in connection with the New River. He also proposed, that the water from 55,000 acres of low level around Whittlesea Mere, which then drained into the Great Ouse, should be brought back to the original outfall, the Nene, at Bevil's Leam. This project was opposed, and ultimately, the district was drained into the Ouse, according to the Middle Level plan of 1844 before-mentioned. The whole of the water

from the 55,000 acres was thus carried round by the Lynn Outfall, 10 miles farther than was necessary for the drainage; whereas if the water had been allowed to drain into its natural outfall, the Nene, the whole country would have been perfectly drained at far less expense, and the Nene might have been effectively improved, without such a severe tax upon the small district of low lands which contributed towards it, as well as the town of Wisbeach.

The Ancholme drainage had already been described by Sir John Rennie in a former Paper, and it was only necessary to say, that the Ancholme was one of those cases where a sluice was carried across the main river, with great advantage. In fact, a sluice was not only applicable, but indispensable, to preserve the drainage and navigation, for otherwise, the strong current of the Humber, and the great quantity of alluvial matter with which its waters were charged, would have so completely overpowered the Ancholme and have filled up its channel, that the whole level would have been inundated, and the navigation would have been destroyed. The sluice, however, was adopted, and both the drainage and the navigation had been most effectually obtained.

Many districts in Yorkshire, such as Hatfield Chase and others, were chiefly drained upon the old plan, and they were still, in many cases, in a very defective state. In 1813, Mr. Rennie made a complete plan for the drainage of Hatfield Chase, which, however, was never carried into effect; though it was believed, that it would have amply repaid the outlay.

He had now finished his remarks on the drainage of this country, and he would merely observe, that the main principles of drainage and navigation were:—the improvement of the rivers and their outfalls;—a judicious system of main, interior, and subsidiary drains, with sluices in connection with the rivers, at the most convenient places for the low-land waters;—and catchwater drains for the high-land waters.

He would not allude to the Irish drainages, because it was a question upon which there were great differences of opinion. The drainage of Lombardy would occupy too much time to discuss it properly. A great deal of money had been spent in that country upon drainage operations, and the attention of numerous scientific men had been given to the subject. The rivers there were upon a much larger scale, and so different in their character, when compared with the rivers in this country, that the same system which had been so necessary here, would not altogether apply there. The rivers, from the repeated raising of their embankments, had become the repositories of the débris and alluvial matter brought down from the Alps, to such an extent, that their beds had, in many cases, been elevated 10 feet, 15 feet, and even 20 feet above the level of the ground which they were intended to drain, so that great expense

was being continually incurred in altering their channels. This was not a good system, but by proper measures the evil might be obviated. He would, probably, have occasion, hereafter, to make some remarks upon this important question, relative to the best mode of preventing the débris from entering the plains, and to the disposal of the alluvial matter by warping, so as to keep the main channels of the river clear. The Indian rivers, also, were so different to those in this country, that they required a specific mode of treatment. In fact, every district, not only with respect to the character and extent of the rivers, but to many other circumstances, required special consideration, and must be treated, each according to its own conditions.

With regard to irrigation, there could be no doubt of its value, and he thought the subject deserved more attention than had, hitherto, been directed towards it; almost the only great work of that character in this country which had been scientifically carried into effect, was that by the Duke of Portland, at Welbeck, in Nottinghamshire, upon which about £50,000 had been expended.

Mr. Fowler said, with regard to the political economy involved in the question of arterial drainage, it had been suggested, that a commission should be appointed, with considerable powers, for carrying out these works. But it might so happen, that among the commissioners incorporated, there would be found some one single individual of great independence, great statistical ability, and altogether so influential as gradually to absorb in himself all the power of this body, and at the same time, he might be disposed to employ unprofessional rather than professional men, to urge the laying down of pipes infinitely too small for their purpose, and in curved instead of straight lines. Now if the whole drainage of the country, and all works connected with it, were at the mercy of such a board, he need not ask whether such a state of things would not bring about evils infinitely greater than those sought to be remedied. It was perfectly true there were cases in which, through the obstinacy of one individual, benefits to others were prevented, even though the proposed measures might also be beneficial to the opposing party himself. That was, doubtless, a great evil, but he repeated, that he did not think such an evil could be remedied, except at the risk of creating greater ones. But it was not only to drainage, that obstacles were sometimes interposed by individuals, but also to roads. It might be desirable to carry through some one's property, a road which would be beneficial to all parties concerned, but if he objected, there was no law to compel his consent. The experience of most men would suggest a vast number of cases where individual obstinacy had caused great inconvenience, but which it might not be wise to make the subject of special legislation. Remembering

what had already taken place, he repeated, that to create a board with such powers as had been suggested, would be productive of evils infinitely greater than those which they sought to remedy.

With regard to arterial drainage, he would attempt to give direction to the discussion by a reference to one, or two principles. He considered the Ancholme drainage a case where the outfall was not dependent upon the discharge of the water from the level itself; and the Witham as a case where it was dependent, but where the tide was shut out. The Ouse and the Nene were cases in which the outfall was dependent upon the discharge of the water from the level, but the tide was admitted. The Ancholme drainage, upon which the Institution had the valuable Paper, presented by Sir John Rennie in 1845, was one in which the tide was not admitted at all. The tidal current of the estuary of the Humber swept past its sluice entrance and kept it free: and it was not dependent upon the discharge of water from the land. The Ancholme was a combination of drainage and navigation, with catchwater drains. The drainage was perfect so far as freedom from inundation was concerned, whilst the means of irrigation were afforded by the catchwater drains: and it combined, better than at most other places, drainage and navigation. Other cases of the kind had been treated upon the plan of Vermuyden, who having a great dislike for tidal water, excluded it wherever it was practicable; and in some cases, he was right. To the Witham, Vermuyden's principle was applied of shutting out the tide above Boston; but in that case it was wrong, because the outfall was dependent upon the mode in which the water was discharged, and consequently, the navigation had been imperfect ever since. At Boston, there was a large expanse of low land, over which the water struggled to get into the deep water of the Wash: the outfall, therefore, was dependent upon the way in which it was discharged. If the water was permitted to go up by the Witham in the same way as by the Ouse and the Nene, the Witham would be in a different condition to that in which it was at present. The Ouse and the Nene might be termed open rivers;—the Nene perfectly so,—and the Ouse, up to Denver Sluice.

The Nene was a river which had been really benefited by the alterations already effected. The outfall was very good, and all that was now wanted was to carry out improvements up the river; and by removing obstructions and properly attending to the banks, it would become a fine river. The Ouse was of a similar character to the Nene, and had fairly repaid all the care bestowed upon it. Every improvement had been of great value both to navigation and drainage. Sir John Rennie had described the large amount of drainage that had been carried out in that district: Mr. Fowler, however, did not think, that 13 feet had been gained at Lynn;

still, at the present time, the Ouse below and above Lynn was a complete river. The cut constructed by Sir John Rennie and the late Mr. Stephenson, was certainly one of the finest engineering works in the country. The cut was 2 miles in length, and from 600 feet to 700 feet in width; and a more successful result had never been obtained. He thought there was no branch of engineering science which required more care, than such cases as this. The material was easily acted upon by scour; and even if cut originally in straight lines, it was easily distorted and turned into irregular forms. That required to be corrected: and it was the province of the Engineer to decide upon the materials that should be used to protect the slope of the cut, upon the form to be given to the slope, and upon the means of maintaining the improvements at the smallest expense. The first depth obtained was seldom so much as was subsequently arrived at. These improvements were obtained at the risk of damage to the banks; as the depth increased, the banks must be protected, and constant watchfulness was necessary to carry them out with safety. In this respect it was impossible to lay down any general principles. The Engineer must consider every case separately, as it occurred to him: but as a rule, a formation of rubble stone at the foot of the slope was a good system, for directing the general current, and the upper part of the slope was kept in form with less difficulty. A minor improvement had been lately introduced into the works of the Norfolk Estuary, by creosoting the stakes; and it was believed, that this small additional expense was attended with advantage. He expressed his entire concurrence with the remark of Sir John Rennie, that it was impossible to lay down any general principle as applicable to all conditions and circumstances. The conditions of every case must be carefully and separately considered: and he especially cautioned Engineers against the adoption, like Vermuyden, of an inflexible principle in all cases.

Sir John Rennie explained, that the Ouse might be considered an open river, not only as far as Denver Sluice, but up to Earith, 20 miles beyond. The gain at Lynn had been 7 feet by the Eau Brink Cut, and a further gain of 6 feet had resulted from the works undertaken in 1850 by Mr. Robert Stephenson and himself.

Mr. James Cooper said, there was one part of the Bedford Level which had been much improved by a large cut, or drain, and other works executed by Mr. Walker, and he would direct attention to that gentleman's Report of 1842, in which he recommended, for the improvement of the Middle Level, the entire separation of the navigation from the drainage. This was a new idea at that time, and one which it was, at first, considered quite impracticable to accomplish. The difficulty arose from the country being very flat, and from the rivers, which had been regulated for the combination of

both objects, requiring to be kept at such a low level, that a drain, it was thought, could not be carried sufficiently low to pass under them, and still have the required inclination for carrying off the water. Mr. Walker succeeded in convincing the landowners of the advantages to be derived by constructing a large and deep drain with a level bottom, and of the great improvements which would be effected in the Middle Level, by the severance of the drainage from the navigation. After much discussion, and a successful, although severe Parliamentary contest, it was determined to carry out a portion of the scheme. A drain was made, about 10 miles in length, passing under one of the rivers of the district, and connected, at its upper end, with two other main rivers. This had the effect of lowering the level of the water 6 feet in the whole of the rivers of the district, thus greatly improving the drainage, and drying up Whittlesea Mere. The principal work consisted of a large outlet sluice at the top of the Eau Brink Cut, having three openings, each 20 feet wide, with the cills 8 feet below low-water mark in the Ouse. The bottom width of the drain was 40 feet at the upper end, and 50 feet at the lower end, with a depth of 9 feet below low-water mark, at the outlet. The course was perfectly level for about 10 miles, passing under Well Creek by an aqueduct, of which the span was about 40 feet; and at that point, sluices were placed across the drain to regulate the water above. Thus the level of the water was completely under command; in summer, it could be kept up for the purpose of navigation and for the supply of fresh water, and it could be allowed to run off in the winter. If Mr. Walker's original scheme had been carried out through the level, the country would have been in a still better condition, for in so large a district, containing 140,000 acres, the interests of all parties as to the proper level of the water could not be consulted. He believed, that at the present time, no portion of the Bedford Level was better drained than the Middle Level. The district was drained in ordinary floods with an average fall, at the surface, of 1 inch per mile, and in extraordinary floods, the average fall was not more than 2 inches per mile.

The carrying out of any general legislative enactment on drainage, would be attended with difficulty, on account of the varieties of opinion which existed on the subject. Throughout the Bedford Level district, almost everybody entertained peculiar amateur opinions upon drainage questions, and it would be found impossible to devise a measure which would be satisfactory to all parties. Considering also the difficulties interposed in other localities by the millowners, it would appear to be better, on the whole, that special application should be made to Parliament, in each individual case.

Mr. HEMANS remarked, that as the Paper led to the inference of some general drainage Act being desirable for England, he thought something more than a passing notice should be given to Ireland, as it was an instance particularly in point. That country had derived considerable benefits from the drainage of a great extent of its surface. From the different railway works which he had carried across the drained districts, he knew there was every reason to be satisfied with the engineering results, so far as they alone were concerned. But the working of the Act relative to drainage had been of a most arbitrary character, and nothing could be more unsatisfactory than placing such extensive powers in the hands of any board. The first step taken was the passing of a Summary Proceedings Act, (partly for the relief of the poor during the famine,) by which power was given to the Board of Works to execute drainage to any extent which appeared, in their judgment, to be desirable, on the application of any single landowner in the first instance, and supported afterwards by a majority at a public meeting. The consequence was, that in a short time, more than one hundred districts were examined and reported upon for drainage. The limit of expenditure was fixed not to exceed, on an average, £3 per acre, upon the whole of the district; but before the works were half completed, the whole of the money had been expended; no results, therefore, were, in the first instance, obtained. Application was then made to the proprietors for their consent to a larger amount of taxation, in order to complete the works. On the refusal of the proprietors, Parliament was induced to institute an inquiry, which was conducted by the late Mr. Rendel, and others, by whose Report it was ascertained, that to complete the works, at least £2,000,000 would be required, instead of £1,000,000, which was the amount of the original estimate. The ultimate measure adopted was to impose upon the ratepayers a tax, to be levied on the amount of the original estimate only; to reduce the works within the extent to which they ought, originally, to have been confined; and to throw the remainder of the expenditure upon the Consolidated Fund. This decision created great dissatisfaction, as it inflicted an unjust burden upon the general resources of the country. But no provision had been made for the maintenance of the works which had been completed. Thus, notwithstanding the favourable circumstances under which this legislative measure was executed, no opposition being offered, and the country requiring labour and improvement, yet it had resulted in failure. Such also he had observed to be the case throughout its working. He did not attribute the blame to the Commission, or to the Engineers who carried out the works,—the fault was in the attempt to legislate

upon the subject in such a manner, conferring arbitrary powers, without imposing proper checks upon a large expenditure.

Mr. FREDERICK BARRY thought there had been some misapprehension with regard to the general way in which arterial drainage in Ireland had been carried out. The first Act was passed in 1842. It appointed the Commissioners of Public Works, in Ireland, Commissioners of Drainage, and it enabled any landed proprietor, on presenting a memorial, and guaranteeing the cost of the survey, to get a report from them upon the drainage of his land along any river, or lake. This report was then to be lodged with the Clerk of the Peace of the county in which the lands were situated, together with schedules and plans; the schedules to state the quantity of land to be drained, their actual value, and the increased value, if the drainage works were carried out, as also the proportion of the expense to be paid by each proprietor upon the completion of the works. The assent of two-thirds of the proprietors was then to be obtained before the works could be commenced. Modifications were subsequently introduced by the Act of 1846, which was passed for the purpose of giving profitable employment to the labouring classes during the famine; and, as the preliminary investigations and surveys were made in a 'summary' way, the object being to afford immediate relief, the Commissioners were not empowered to expend more than £3 per acre, without again collecting the assents. These assents not having been given in eleven districts, a Commission of inquiry was issued; but he did not think they reported, that £2,000,000 would be required to complete the works, as he found that, up to the 31st of December, 1858, the total expenditure in one hundred and twenty-one districts, of which one hundred and ten were completed, and the remaining eleven nearly so, was only £2,342,746.

It had been inferred, that no power was given to maintain the works after completion. In this he did not agree, as, after the district was handed over to the proprietors, the latter had, under the Drainage Acts, authority to maintain the works. For that object they elected trustees amongst themselves, appointed their own Engineer, and fixed the amount to be raised for maintenance and repairs. He saw no reason against passing a general law on the subject, permitting, under certain conditions, the proprietors of flooded and injured lands to execute works for their relief and to levy rates, the Board of Trade acting as arbitrators in cases of dispute.

In conclusion, he would mention, that in Ireland, up to the end of 1858, there had been 1,450 miles of river channels excavated and scoured, unwatering 6,372,000 acres, nearly one-third of the whole country, by which means 284,577 acres of land had been

freed from flooding. One hundred and ten districts had been completed, on which awards had been made, showing that 145,000 acres of land had been drained, at a cost of £5. 19*s.* 11*d.* per acre, the increase in the annual letting being £40,000.

Mr. BIDDER, V.P., said, that in the course of the discussion, some remarks had fallen which called for observation. It seemed to have been inferred, that the Irish Commission was a great financial success, because 175,000 acres had been drained at a cost of £5. 19*s.* 11*d.* per acre. Now that represented a capital of about £1,000,000; and, as the rental value of the land was stated to have been increased £40,000 per annum, the return upon the outlay was only 4 per cent. He could not, therefore, regard that instance as at all favourable to the establishment of a Commission of such a character as that which had been described.

He regretted, that the discussion had been rather of a political than of a scientific character. The object of the Institution was to promote scientific and practical discussions; those of a political character being purely incidental. On this part of the subject he would only remark, that both as an Engineer and as a citizen, he was decidedly opposed to all centralisation. Human nature was, no doubt, a very imperfect agent to deal with; still it was, in many respects, superior to the artificial systems intended for its control.

Although the subject had been introduced with great care and research, and although a most interesting narrative of drainage works had been added by Sir John Rennie, yet further discussion upon scientific facts was highly desirable. An exact statement of facts in the treatment, whether right, or wrong, of any one river, was of infinite value; whether it was a tidal scour, or backwater from land streams, the relative value would be of vast importance; and he hoped another Session would not pass over, without this subject receiving the attention which it deserved. Sir John Rennie had stated, that the effect of the Eau Brink works had been to lower the water 7 feet at Lynn; such might have been the case at the upper end of this cut, but at Lynn the datum line had risen. It had again been lowered 6 feet by the operation of the New Cut; but the water at Lynn was certainly, at present, not 13 feet below the level at which it stood, before the Eau Brink Cut was made: he thought it had not been reduced more than 4 feet. He alluded to this, in order to show the absolute necessity of a correct and complete record of the phenomena which had occurred, in every river the bed of which had been altered.

The arterial drainage of the country was of the utmost consequence; but the results said to have been obtained were most anomalous. It had been asserted, that in some instances, the effect of under-drainage had been to swell the rivers, and to cause

more water to flow from the land. He doubted, however, whether floods would be increased by under-drainage, or whether more water would flow off the surface of the land. Although contrary to preconceived opinions, and the result of *à priori* reasoning, he rather believed, that under-drainage would diminish the extent of floods, that a greater quantity of water would be evaporated, and that, consequently, less would be discharged into the rivers.

Mr. W. A. Brooks was desirous of obtaining some information, which he believed to be in the possession of several Members, with reference to the levels taken for the drainage of the eastern fen districts; he wished also to know how far the alterations which had been made since the year 1767, had affected the great streams of that district. A vast tract, extending 40 miles from the ancient seaboard, had been converted into land fit for agricultural purposes, partly by deposits of sand of marine introduction, and partly by alluvial deposits. Referring to the levels taken by Elstobb and Smeaton in 1767, he found, that at the east end of Kinderley's Cut, (which was the first work constructed,) there was, at that time, a depression of 14 inches in the high-water level, which he attributed to the contracted nature of the channel. That depression showed the necessity of having ample waterways, which he considered had been too much neglected in the great works in Cambridgeshire, Norfolk, and Lincolnshire. At the Horseshoe Hole there was a depression of 2 feet 1 inch; at Wisbeach Bridge, of 2 feet 3 inches; at Cold Harbour, of 2 feet 10 inches; at Guyhirne, of 3 feet 11 inches; and at Knar Lake, 9 miles above Wisbeach, to the extent of 6 feet. The last was a depression equal to the spring-tide flow of the Red Sea at Suez; and if the same amount of depression took place throughout the proposed cut at the isthmus, there would be no lift of tide, or tidal influence experienced at a distance of 17 miles from the Red Sea. In a Report by Sir John Rennie, in December, 1836, it was stated that, as a result of the improved drainage, there was a depression of the low-water surface to the extent of 10 feet at the North Level Sluice, and that sluice had been placed 8 feet lower than the Old Gunthorpe Sluice. Now, the old flow of the tide, by the levels to which he had referred, was 12 feet 7 inches, which, added to the 10 feet, would give 22 feet 7 inches as the height of the column of water, or tidal flow, supposing that the high-water level remained the same as in 1767; but Sir John Rennie gave, by his levels of 1836, a flow of only 16 feet 10 inches, which would show at that place, a depression of 5 feet 9 inches of the high-water surface. It was very desirable to have this difference, or increased depression of the level at high water, correctly ascertained; and he hoped, by mentioning the subject, it might lead to the produc-

tion of the levels of the Old Eau Brink Cut, or of the Ouse in its ancient and in its present state; and also of other valuable documents in connection with the River Witham. He thought those long narrow cuts in the Nene and the Ouse courses were not likely to be very successful; there would be a very confused navigation at the outfalls. He believed it would be desirable, that an enlargement should be made, to allow a greater influence of the tidal element, in the new channels which were laid down on the plan. (Plate 2.) If those long narrow channels were carried out, a great depression would take place in the level of the tidal column, entering each channel.

Mr. J. Cockburn Curtis said, that the question of the improvement of tidal drainage was a question of measurements and facts. He was glad to learn, that Mr. Brooks proposed collecting and discussing the tidal observations which had been made in reference to the Norfolk Estuary and its dependent drainages, and he should be happy to place at his disposal, for that purpose, the observations which he had made, when called upon by the Eau Brink Drainage Commissioners, in 1849, to investigate the subject. In order to ascertain the extent of improvement, the only philosophical and logical mode of proceeding was, to compare the physical state of a drainage with its previous condition at different epochs of its history, and to consider the combination of elements at work, constituting what might be termed the natural economy of the estuary, in relation to itself alone, and to no *à priori* test. The facts would, of necessity, present themselves with endless variety of combination, and with every shade of difference; and it was possible that, in the present state of hydraulic science, there was no department of the profession in which the Engineer was so strictly called upon to divest himself of all preconceived notions, and to confine himself to the investigation and application of the facts and physical laws of the individual case before him, as in questions of this character.

There was one point in connection with the Norfolk Estuary improvements to which he would call attention, and which forcibly struck him during his examination of the Nene and Ouse improvements. He alluded to the importance of designing the outfall of a tidal drainage in such a manner, that the artificial channel where it debouched into the estuary, should be, with regard to direction, slope, and section, in harmony, as nearly as possible, with the natural tidal conditions of the estuary and of the natural deep-water channel which formed the principal axis of the incoming tidal wave; where this had not been attended to, he had generally noticed, that a low-water bar was formed, and that the outfall pursued an uncertain and tortuous course until it reached the deep-water channel.

Where a straight cut was substituted for a natural channel of greater expanse and curvature, it was obvious, that the fall became suddenly concentrated on a small portion of the length of the channel, and the downward motion of the water would have a tendency to 'plough up' a bar at its termination: this could only be avoided by increasing the width and sectional area of the low-water channel as it entered the estuary, so as to bring the slope of the water passing down the cut, at its lower levels, in unison with the natural slope of the tidal wave in the estuary. The width of the channel had been increased in this manner, to a certain extent, in the case of the Nene, and he believed also in that of the Ouse Outfall, but not sufficiently in either; and in both cases, the direction of the channels had not been designed with sufficient regard to the principal axis of the in-coming tidal wave. At the time of Mr. Curtis's examination of the Nene Outfall, there was a low-water bar of the character he had just described, at a short distance beyond the termination of the new low-water channel, and in giving evidence before the Committee on the Norfolk Estuary Bill, he pointed out, that with the dimensions and direction then proposed, a similar result would, probably, take place at the new outfall for the Ouse. He had not had a subsequent opportunity of inspecting the locality, but from the Admiralty Chart and Sailing Directions, compiled since the execution of the works, he was led to think, that his opinion had been justified by the existing facts of the case. It was with great diffidence, that he ventured to make those remarks, upon works designed by the eminent Engineers who had executed the improvements of the Nene and Ouse Outfalls. He by no means wished to undervalue the great advantages which had, doubtless, accrued from their execution, both to navigation and to drainage; his object was simply to point out certain elements, which, he thought, had not received sufficient consideration, and by attention to which it was possible, that a much greater extent of improvement might have been obtained, at an equal, if not at considerably smaller expense.

The investigation of a great number of tidal observations on different rivers and estuaries had led him to notice the importance, in certain cases of tidal drainage, of preserving, as far as possible, the character and volume of the tidal wave, in its passage up and down a river. In such cases it was not only necessary, that a critical examination should be made of the river, in its high and its low-water states, but the whole profile of the wave should be observed, in its passage up and down the river, at as many stations as possible. Such observations, when reduced in the ordinary manner to diagrams of time, height, and distance, and compared with the profile and volume of the derivative wave, never failed to show any irregularity, or diminution of the tidal

force; and by such a process, the whole of the tidal facts of the case became vividly impressed on the mind.

Tidal drainage might be considered as a race against time, and in some rivers more water was discharged out of the river by the rapid reflux of the tidal wave, than could possibly be discharged by the slower action of the current, or stream; hence the importance of proportioning the tidal mouth of a drainage channel to the tidal conditions of the estuary into which it debouched, and the necessity for maintaining the outfall free from bars, so as to preserve a clear entrance and exit for the lower portion of the tidal wave.

There was no doubt, that the theoretical determination of the form of a channel which should, under given circumstances, exactly answer the conditions of discharging a given amount of fresh-water drainage, and yet preserve the greatest amount of tidal force was, in the present state of tidal hydronomy, a difficult problem; still he thought it could always practically be done, by a careful observation of the physical forces at work at the land and seaward ends of the proposed channel. The law of motion of the tidal wave had, to a certain extent, been determined in relation to channels of uniform depth and section, but he was not aware, that any attempt had been made to determine the law of the change in its volume, due to the friction of the slope, curvature, or variation of section of the channel through which it passed. He had little doubt, that with a sufficient number of tidal observations, these elements of the computation could be ascertained, and that hence laws might be established, whereby the best form of channel for the conservation of the tidal force could be determined with theoretical, as well as practical exactness.

The Thames was frequently cited as an example of a theoretically perfect river; it was also stated, that from recent observations, the tides at London Bridge rose and fell from 4 inches to 6 inches above and below the corresponding levels of the same tide at its entrance. As far as his knowledge at present extended, he thought, that under similar conditions, such a channel, gradually enlarging seaward, was best calculated for the upward and downward propagation of the tidal wave.

Although from an early period he had been placed under circumstances which had practically familiarised him with the forces and motion of water, and the subject had always been to him a matter of study and interest, he should not have ventured to put forward his views, except for the candid and encouraging tone of that portion of the President's Inaugural Address[1] which

[1] *Vide* p. 219. Mr. Bidder had been elected President, and had delivered his Inaugural Address before the conclusion of the discussion.—Ed.

related to Hydraulic Engineering. He hoped, that others who possessed greater and more mature knowledge than himself, would also respond to that call, and by the mutual contribution of the information and experience already possessed, rescue that branch of the profession from the stigma of empiricism, which, although to no small extent justified by want of sound knowledge on the subject, was one which, it must be remembered, could be wiped away by the careful discussion and classification of well-established facts, and their reduction to natural laws.

Mr. Ormiston was not well acquainted with the subject of land drainage, his attention having been principally directed to river improvements. He was, for some years, connected with the Clyde, which had been more improved than any other river. Those improvements were commenced about the year 1768, under the direction of Mr. Golborne. Up to that time, little inconvenience appeared to have been felt from the land floods. The improvements then proposed and shortly afterwards executed, consisted in narrowing the river, so as to give more scour to the channel. The channel was certainly deepened, but its capacity to discharge land floods was, at the same time, materially lessened. This soon became disagreeably evident, in the increased height of the land floods, the highest of which, on record, took place in March, 1782, when the water rose 18 feet above high-water of spring tides, overflowing a large portion of the low part of the city of Glasgow, and the surrounding country, and doing great damage. The evil continuing, in 1799, Mr. Rennie was consulted upon the causes of this increased height of the land floods, which, by the local authorities, were, in a great measure, attributed to a weir, or bank of stones, which had been thrown across the river to protect the foundations of Glasgow Bridge. He reported, that the weir had not materially affected the river, and that the principal cause of the floods was the increased drainage of the country above Glasgow; that he believed the improvement of the river would give some relief, but that it was not to be expected, that the floods would ever fall to their old level. The improvement suggested by him, and carried out, gave an increased area to pass off the floods, and somewhat reduced their level; still every winter the quays were flooded, and it was not until recently, that complete relief had been obtained, by carrying out, under Mr. Walker's direction, the great improvements in widening and deepening the channel according to his plans, for which an Act had been passed in 1842. The depth of the river had been increased from 18 inches, or 2 feet, as Golborne found it, to 20 feet; and at Glasgow, to one place which was the gorge of the river ten years ago, at least three times the sectional area had been given. One effect of the improvements had been to reduce the low-water line 8 feet,

and, so far as land floods were concerned, instead of their rising to the height mentioned, they now seldom reached to more than 6 feet above high water; the quays and town, consequently, were no longer flooded. Another advantage was, that the floods ran off in a very short time. The lines adopted were laid down on precisely the principle advocated in the discussion;—a gradual widening as they approached the frith, with easy bends and a regular bottom.

Mr. Locke, M.P., (Past-President,) observed, that Mr. Ormiston would materially add to the value of his remarks, by furnishing the Institution with a chart, or plan, indicating the improvements in the Clyde since 1842.

Mr. Leach offered some remarks upon the improvements in the Thames, which had undergone considerable alterations during the last thirty years. The removal of Old London Bridge must be considered as having had a great effect in producing these alterations; but he thought more was attributed to that cause than was strictly due to it. He estimated, approximatively, that the quantity of material dredged out of the river, westward of London Bridge, since the removal of the old bridge, had been 6,000,000 cubic yards, and he attributed the lower level of the ebb tide quite as much to the dredging out of material, as to the removal of the old bridge itself. The difference in the low-water level at Teddington Lock, which was the end of the tidal flow, was, from 1810 to the present time, 4 feet 10 inches, and in the last 14 miles of the upper portion of the tideway, there was a very considerable depression of low water. There was, consequently, a much larger amount of tidal water than formerly, but he had not found any material change in the level of high water; not more, indeed, than was fairly attributable to the greater momentum which the tide retained, in consequence of the removal of the obstructions occasioned by the old bridge. Little had been effected for the upper part of the tidal way of the Thames, which still required improvement; but he knew, that it was the intention of the Conservators of the Thames, as soon as circumstances would permit, to turn their attention to this subject, with a view of creating an effective depth for navigation, throughout the whole extent of the tidal range. Other parts of the river beyond that range had been altered, within the last thirty, or forty years. Several weirs had been erected, from which an injurious effect upon the drainage of the adjoining land had been anticipated; but in the majority of instances, the result, on the contrary, had been to give an increased value to the land. In the part of the Thames to which he alluded, it had been observed, that where these weirs did not raise the water higher than 4 feet below the level of the meadow lands, the productiveness was increased. Below the weirs, the surface of the

water had been depressed, and the drainage of the adjacent land thereby improved. The attention of the Conservators had been directed towards obtaining correct tidal observations, in order to judge of the effects of the works which they had in contemplation. He did not expect, that the level of ebb tide would be diminished below Westminster Bridge, but he thought, that above that point, the improvements would have the effect of materially depressing the level of low water.

Mr. Locke, M.P., inquired whether the level of low water at Teddington Lock had been affected to the extent of 5 feet, or that the flow of the tide was 5 feet lower; as also, whether there were any recorded observations of the flow of the land water over Teddington Lock.

Sir John Rennie inquired whether the Corporation of London had established any system of gauging so as to afford correct data, and if so, what was the difference in the high-water level, occasioned by the removal of Old London Bridge. The late Mr. Giles had stated, from personal observation, that the difference was then about 10 inches, or 11 inches; he wished to know whether, from observations subsequently made, the tide had still further increased.

Mr. Leach replied, that the ebb became 5 feet lower from the year 1810, but the depression had principally occurred, since the removal of Old London Bridge. He had gauged the flow of water over Teddington Lock, but he had not been able to arrive at any satisfactory results. His impression from observation was, that the water discharged amounted to about 500,000,000 gallons in twenty-four hours. The Corporation of London, whilst they were the Conservators of the river, had established a few gauges, and had been about to increase their observations to a considerable extent; the standard to which all those which had been collected were referred, was the Trinity level of high water. The high-water level above London Bridge, as far as he could judge from facts that could be ascertained, had not been materially affected by the removal of the old bridge, or by the subsequent dredging that had taken place above it.

Mr. Locke, M.P., said it had been stated, that notwithstanding the removal of 6,000,000 cubic yards of material from the Thames, the high-water level had not been materially changed, but as the river had been, at the same time, affected in other ways, it was still desirable to ascertain whether the dredging of so large a quantity of the bed of the Thames might, or might not, have affected the level of high water.

But the discussion had wandered away from the original question of drainage. It was the object of the Paper to show, that by certain operations in the fens of Lincolnshire and in some districts in the west of England, considerable tracts of land had been

brought into cultivation, by shortening cuts, by making straight channels, and by lowering the level of the water. That was a very different question from the improvement of tidal harbours, the object and intention in the improvement of which was, generally, to raise the level of the tide and so to increase the depth of water; the object of drainage being, on the contrary, to lower outfalls, and thus more effectually to get rid of the upland waters; and these two objects were sometimes antagonistic. Whilst, therefore, discussing the question of drainage, it was important not to misconceive terms, but, like metaphysicians, first to define the terms, or objects to be aimed at. It appeared to him, that the Paper itself had been lost sight of, and the reference to the effects of the removal of Old London Bridge and the conditions of the tides in the Thames, had little bearing on the drainage of lands, and the best means of bringing them into a state of cultivation. Whilst one class of operations might be useful and valuable for one object, they might be detrimental for the purposes of the other. The operations in the Thames and in the Clyde could afford neither an answer to, nor a refutation of assertions made in the Paper, with respect to those undertaken for a totally different purpose, that of bringing fresh land into cultivation. The improvements of the Nene might have been carried on with a double object, for draining the lands as well as improving the navigation; but the sole object of the improvements in the Clyde was to create a harbour at Glasgow. He was delighted to hear, that those magnificent works had increased the depth of water at Glasgow, from about 18 inches to 20 feet, and it reflected great credit on the Engineer who could, by artificial means, produce such results. But the improvement of the Clyde had little, or no reference to drainage, which sought for the means of permanently lowering the level of the outfall; whilst in the other case, the object was to raise the tidal stream, and thus to improve the navigation. It was important, in this discussion, to have a distinct issue; to determine the best means of establishing a tidal harbour, and the proper methods of drainage for the recovery of land, the importance of which was felt by no one more than by himself.

Mr. William J. Clutton, as a land agent in the north of England, had lately to drain large areas of land for farming purposes, and he would draw attention to a few of the difficulties he had encountered. A great deal of the land upon which he had operated was in the vale of York, and exceedingly flat; that and other parts of the county not being more than 25 feet above mean-water level at Liverpool. The object in view was not only to bring fresh land into cultivation, but to prevent the loss, for want of drainage, of the old land. Many large districts in Yorkshire were under water for weeks together, but they were

capable of perfect drainage, if the co-operation of all the parties interested could be procured. During the last two years he had been engaged in various cases, involving more, or less litigation, in order to compel the occupiers of lands bordering upon streams for a length of three miles, to put those streams into a good state of repair, and to keep them within their old and proper beds. The effect had been to relieve about 400 acres of land; but as the proprietors acted under compulsion, they merely did that for which they were legally liable at the time, and although the works of repair, which were only executed in 1857, would have continued efficient, if they had been maintained, they had been allowed to relapse into their former state. It was imperative, that some means should be adopted, for compelling those who had land on the outfalls of large districts of country, to keep those outfalls in such a condition, that no injury should result to their neighbours. At present, it was frequently impossible to drain, because there was no power to compel the parties below to fulfil their obligations, and to keep their rivulets sufficiently clean, deep, and wide, to carry off the surplus waters which the old outfalls would discharge, if they had been kept open to their full dimensions.

Mr. BEARDMORE remarked upon the suggestion for creating some Government inspection, or supervision of drainage operations, that there was already in existence an Inclosure Board, but, according to his own observation, that Board did not stipulate for the perfect drainage of inclosures which they sanctioned. It appeared of the utmost importance, that every new inclosure should have most efficient provision for all future drainage. Certain preliminaries were gone through, but amongst all the queries of the Board, it was not thought necessary to put the question,—Have you provided, or are you providing for the thorough drainage of the lands to be inclosed? If the supervision of the Inclosure Board was to be maintained, or that of any similar body should, hereafter, be resolved upon, the sooner that desideratum was added to their requirements, the better.

He differed from the opinion which had been expressed, that the tidal question should not be mixed up with that of the drainage of lands. The lowering of an outfall for drainage, if the tide was to be admitted, could not be considered, without taking into account the effect of its admission. If outfalls of that character were lowered, the new conditions which the tidal water must assume, should be carefully examined. The spring-tide high-water of the Nene, at Peterborough, stood in 1850, from 2 feet to 3 feet below the same high-water at Wisbeach. When the Commissioners began to open the channel at the latter place, it was generally expected, that the tide would rise higher, and damage the barrier banks, which were assumed to be not

sufficiently high. Much alarm was thus incidentally caused to the neighbourhood, from the lowering of the level of low water at Wisbeach, which was intended for the purpose of clearing floods, and of draining about 3,000 acres of land below Peterborough. In lowering tidal outfalls, and those of an ordinary upland river, very different conditions presented themselves. So far as the maintenance of tidal estuaries was concerned, the preservation and regulation of the tidal flow was, in his opinion, infinitely more valuable in its effect than that of back water. The present state of things, and the means of dealing with them, were utterly dissimilar from those which existed forty years since, when the steam dredger had not been introduced. No upland water could be compared with the volume of additional tidal water and the regulation of its flow, afforded by the 6,000,000 cubic yards which had been dredged out of the Thames, inasmuch as the tidal flow had the superior advantage of acting in alternate directions, without the disadvantage of silt which was attached to flood waters. The condition of this river had not realised the serious predictions to which the removal of Old London Bridge had given rise. Its removal had, undoubtedly, thrown the tide higher up, especially in respect of its culminating point; but he believed the enormous dredging which was carried on, had greatly tended to keep down the flushing of the tide, to flatten, in fact, the profile of high water by the increased sectional area. He could say, with some degree of certainty, that the tide did rise higher below London Bridge by 6 inches; and the average above the London Docks was, probably, from 4 inches to 6 inches higher at spring tides, than before the removal of Old London Bridge.

Mr. Hawksley said, that the Paper, as he understood it, was essentially a Paper upon agricultural drainage, but he agreed with the opinion, that it could not be fully considered, without treating also of a variety of other drainages. So intimately was agricultural drainage connected with the others, that no discussion upon the subject could be complete which did not take into account, not only agricultural drainage, but also ordinary river drainage, tidal drainage, and even town drainage; because, so far as town drainage was concerned, it was very intimately mixed up with the question of outfall and the benefits of agricultural drainage itself, and especially so with regard to the questions which arose in connection with the Metropolis. A great error prevailed with regard to the under-drainage of land. In many parts of the country the land was over-drained. It was quite possible to remove too much of the under-water, or in other words, it was possible to remove it to too great a depth from the surface. It was possible to produce such an arid condition of the surface, as to render it unfit for the growth of several descriptions of

crops, of which the most distinct proofs were to be found in the fen districts. In the winter, these districts were drained as low as the level of the outfalls would permit; but in the summer, the crops deteriorated if the water continued, during the hot months, to drain off to the winter level. To remedy this the farmers not only obstructed the delivery of the water, but in many cases, they brought water to feed the ground from the adjacent rivers, through the drainage; because they found, that if they reduced the water to more than 30 inches, or 36 inches below the surface, the weight and succulency of the crop was less than if the water was kept up to that level. Such was the case over no less than 500,000 acres of land; and if true over half a million acres in the fen districts, it was true, more, or less, over all parts of the kingdom. He had observed, that in many places, there were persons professing to have great theoretical knowledge of drainage, who everywhere adopted their own peculiar systems, without regard to the differing qualities of the soil and the varying circumstances of the case, one advocating a systematic deep drainage of 5 feet, another, a systematic deep drainage of 6 feet, and so throughout. All such dogmatism was exceedingly wrong. In dry weather, the stiff clay lands became hard and cracked, and in such instances, the replenishing rain waters would run through the cracks into the drains. The ground was not properly fertilised, and it would not, in consequence, bear full crops. In Worcestershire, where there was a stiff surface soil with gravel underneath, they had, in many instances, cut through the pan of the gravel and let off the water from below; the result was, that the weight of the crops was much diminished. It had been alleged, by Liebig and others, and with some truth, that by carrying the water too rapidly from below, the soil was exhausted of many of the salts. No doubt such was the fact, and that great damage was inflicted in that respect by over-drainage; the soil might be washed by means of the rains until nothing was left in it but what was insoluble. On the other hand, if land was not drained sufficiently, the capillary attraction would draw up the moisture from below, great evaporation would occur from the surface, and the land would not only be kept cloddy, but its temperature would be materially reduced. He knew a case in the north of England, where the land was very moist; but when it was afterwards drained, the temperature of the soil had risen 7°, a result equal to the removal of the estate 200 miles, or 300 miles further south. But it was not beneficial to remove so much of the feeding moisture of the land, that green crops could not grow upon it, and the plants themselves must exhaust their powers in making long fibrous roots, in order to penetrate the land to a great depth for the purpose of deriving nutriment.

The next subject which had been discussed, and which formed a leading topic of the Paper, was the difficulty under which certain agriculturists and landowners laboured in removing the water from their estates, because other proprietors lower down would not concur in the improvement of the general drainage; but this grievance was alleged very much upon the same principle, on which the waggoner appealed to Hercules to lift his wain out of the mire. Why should Government be called upon for relief, in cases of this nature? He thought there was nothing more improper than the interference of the Government with private rights; it was the very worst principle that could be adopted; it was bad for the Government itself, bad for the proprietors, and bad for the public. There was no difficulty in effecting this object, if the efforts were properly directed. It generally happened in these cases, that those who were anxious to drain their lands wished to do so at the expense of others, although there was little difficulty in accomplishing the object, if they would only pay for it. If they would recompense the proprietors below, they could generally get a road through, and could improve the watercourses. A man who had bought a water-logged estate for £20 per acre, and was desirous, by cutting fresh outfalls, to increase its value to £100 per acre, complained of the injustice of his neighbour, because he would not allow the water to pass through his land, and called for the interference of the Government to compel him. Now there was no just reason for such complaint; the man held his land under certain natural conditions. If he wished to convert it from those conditions, he could, in general, easily accomplish his object by the expenditure of the necessary amount of money. But in most places there was already in existence, or could be brought into existence, a valuable commission, under an enactment of Henry VIII., called the Sewers Commission, which had charge of all watercourses in the locality; by setting that Commission in proper operation, it was possible for any person to get his land drained, so far as he had the legal right to do so. If he wanted more than these legal rights, Parliament was the proper tribunal to apply to. If an appeal was made to the Secretary of State, as he could not personally hear the parties, visit the locality, and investigate the case, he would, probably, send down some inferior person imbued with his own peculiar notions, who would make a report behind the back of all the parties concerned; the Secretary of State would then act upon that report, and make, perhaps, an order affecting the property rights of, and coercing individuals, who would be little, if at all, benefited by this particular operation. To show how unjust and impolitic such a course would be, he might mention the case of the supply of water to the Metropolis. Five, or six years ago, that subject underwent a long Parliamentary

investigation during two whole sessions, and during the course of the inquiry several gentlemen connected with the Government, and others not so connected, brought forward certain schemes. Now, if the matter had been left to the decision of the Government, and if any of those gentlemen had been at the head of the department, his own scheme, and no other, would have been permitted; the consequences would have been still worse, if by any chance, one of the competitors should have been afterwards nominated to the place of the first. If the Government could act, it was utterly impossible for it to decide upon the relative value of schemes of this character; and if compelled to act, nothing but dissatisfaction would be the result. The carrying out of similar projects should be left to private enterprise, assisted by proper local authority unconnected with Government.

He differed from the opinion, that the consideration of the upland waters was of little importance in this question; he thought, on the contrary, that they had a very great and beneficial effect. He quite admitted, that in estuaries, and in rivers discharging into tidal estuaries and within tidal action, the tidal water played the principal part in the operation; but, supposing there was no upland water, the action of the tide would gradually cause the deposit of matter at the head of the channel, and contract its length, until, finally, it would become obliterated. In a channel where there was a small amount of upland water, the tide flowed and ebbed in the same quantity, but the ebb would, in general, preponderate, because of the addition of a certain amount of upland water. If that amount was so small, that it could not of itself, or even in conjunction with the tidal water, produce a sensible effect upon the scour, yet, small as was its quantity, it would determine the advance to the sea of any matter removed by the tide; under those circumstances there would be no deposit at the head of that channel, which would keep itself open for ever. He considered it important, therefore, to secure as much upland water as possible at the head of the stream. If the quantity was large, it would, added to the operation of the receding tide, and under many circumstances, deepen the channel. If, for instance, the quantity of tidal water was 20, and the quantity of upland water only 1, then, inasmuch as the scouring action was in proportion to the squares, the scouring effect of the receding tide would be greater than the effect of the incoming tide, by 10 per cent. He had no doubt, that a similar action was produced in the Thames, especially since the removal of Old London Bridge, and was at the present moment operating with good effect.

As Old London Bridge had been referred to, he might call attention to a point which had not been mentioned. Before the old bridge was removed, the fall there amounted to 5 feet. The

reason why the high water had not been found to be materially increased was, that a large amount of water was formerly held pent-up behind the old bridge, and consequently, it was not necessary, at that time, for so much water to pass beyond London Bridge as at present, in order to bring it up to the high-water mark. Reference had been made to the quantity of water flowing down the Thames in dry weather. About ten years ago, during an extraordinarily dry season, he had occasion to gauge some of the weirs; on that occasion he had ascertained that, instead of 90,000,000 cubic feet passing over Teddington Weir per day, as in the case in ordinary seasons, there only passed over about 60,000,000. He had also ascertained since, by a great number of comparisons, not only of the Thames, but of the chalk lands draining into it, that the whole quantity of water drained from the valley of the Thames into the sea, did not exceed a depth of 6 inches per annum. The fall of rain was not disposed of, as had been represented, in three equal parts: one-third lost by evaporation, one-third passing into the rivers, and one-third disappearing altogether. The evaporation was nearly a constant quantity, averaging about 15 inches, and inasmuch as the average rainfall near London was about 23 inches, and in some cases as low as 18 inches, it followed, that there were only a few inches which passed to the sea. Such, he believed, were the actual results, as nearly as could be ascertained from the discharge by the rivers.

With regard to the formation of bars, and the advantage of curved channels, he confessed, so far as the effect of artificial works upon the inland channels of the country was concerned, all his experience and all his calculations went to prove, that the straighter the channel, the greater would be the effect produced. The tide would come up with greater ease, and the water would go out to a lower level, by a straight channel than by a curved one. Bars were all produced upon the same principle, by a very simple operation. Matter in mechanical suspension was brought down the river, under circumstances which enabled it to be borne by the current, till it got into a wider place, where the velocity of the water was diminished; and the absence of motion caused the deposition of the matter at the mouth of the river, forming impediments to navigation, which could only be removed by artificial means.

Mr. Manning,—through the Secretary,—expressed his intention, at some future time, of laying before the Institution a Paper on the Arterial Drainage of Ireland. He would confine himself at present to the correction of two errors which had arisen relative to those works. First, that the Report of the Government Commission, published in 1853, gave a full account of all that had been done up to that time, the area of lands subject to floods being

77,546 acres. This statement was only applicable to eleven, out of one hundred and twenty-one districts, then either finished, or in course of execution; the fact being, that at the close of the year 1852, 205,032 acres of land had been already drained, and about 130,968 acres more were in progress, making a total of 336,000 acres. Secondly, that the great defect in the system was, the absence of any provision for maintaining the works and keeping them in repair after the first year. Now, on their completion, the Commissioners of Public Works in Ireland made an award, which allocated the proportion of the expenditure to be repaid by each proprietor, including the cost of one year's maintenance, in advance from the date that the district was handed over to a Board of Trustees. To this Board, composed of, and elected by proprietors, was given, by Act of Parliament, the power to levy, thereafter, such annual rate as was necessary for the repair and maintenance of the works; and, in case of their neglect, or refusal to act, the Commissioners of Public Works were, on certain forms being complied with, empowered to cause such works of maintenance to be executed, and to levy them upon the proprietors, in the proportions set out in the final award.

Mr. Bailey Denton,—through the Secretary,—remarked, that it had been inferred from the observations he had made, that he had advocated the establishment of a central commission to carry out, compulsorily, the vast work of river reform and mill compensation: now this was far from his intention. His experience in drainage works had so frequently made him acquainted with the want of outfall, by the accidental interposition of a neighbour's land, which must be crossed to secure a discharge of injurious waters,—with the defective character of the shallow and tortuous watercourses which now existed, (without any reference to mills,) —and with the inability of a majority of improving landowners to bind even a single objector to any work, were it ever so desirable, that he was personally inclined to confine his efforts towards obtaining a remedial measure dealing with those minor evils by themselves, rather than to complicate the question by connecting them with those of main rivers and mill compensation, although he felt convinced, that ere long, that very important subject would force itself upon public attention. No one connected with drainage would think of delegating to a central board, sitting in the Metropolis, the execution of works of arterial drainage; at the same time, no one acquainted with the working of the Tithe Commission, the Inclosure Commission, the Copyhold Enfranchisement Commission, and the Under-drainage Commission, could doubt, that a central commission to administer a general Act for the improvement of outfalls, with power to appoint Civil Engineers duly qualified to act as Assistant Commissioners, would fully meet the requirements

of the case. With the Inclosure Commission, the actual work of inclosing and allotting was performed by persons appointed by the landowners interested, the duties of the Commission being simply to see, that the Act of Parliament was complied with. So it might be with a commission for the improvement of outfalls; the landowners might appoint their own Engineer, and the Commissioners simply facilitate his operations by the legal administration of the Act.

In bringing the whole subject before the Institution, the Author had given an opportunity of suggesting the best mode in which the Legislature should deal with it, and he submitted, that it was of the greatest importance to the country, so largely interested in this important matter, and to numerous members of the engineering profession who might be most profitably engaged in agricultural drainage, that an opinion on the legislative part of the subject should not be withheld; for so monstrous were the evils continually arising, that it could only be a question of time when the remedy should be supplied. It was the opinion of many, that each evil should command its own remedy, and that a special Act should be obtained for each district drainage and each separate outfall; but those who had acted on commissions of this sort knew full well, that the immense waste of money in Parliamentary proceedings and the practical evils resulting from the incompetent character of the tribunals before whom these measures were brought, prevented any very general adoption of such a system. The cost of the Act for the Middle Level Drainage, 1848, was £10,990. That of the Norfolk Estuary Acts had been £40,112. 10*s*., one-third of the amount of the contract for the whole of the works, which was £142,000. The eight Acts of the Eau Brink Cut could not have cost less than £100,000, and a striking fact with regard to them was, that those eight Acts, had now become obsolete; the Commissioners were seeking to repeal the whole, and to establish a system of conservancy more in accordance with the existing state of things. But the cost of, perhaps, the most recent and certainly the most unsatisfactory, specimen of outfall legislation, was the Nene Valley Drainage. In that case, £30,083. 0*s*. 10*d*. had been expended in Parliamentary proceedings, yet the progress made in the works rendered it so doubtful whether any benefit whatever would result from them, that the landowners were now disposed to let matters remain as they were, rather than involve themselves further, by another application to Parliament. The extent of land to be benefited by the Nene drainage was, at the utmost, 16,000 acres, so that nearly £2 per acre had been expended in Parliamentary proceedings alone. How strangely did this contrast with the fact, that the average actual cost of under-drainage was only £5 per acre, including all expenses, and that

the average cost of the administration of the Under-drainage Commission did not exceed two shillings per acre.

Doubts had been expressed, whether the extension of under-draining had the effect of increasing the floods, and of diminishing evaporation. He proposed, at some future day, to present to the Institution the results of some experiments he had undertaken in order to arrive at correct conclusions on those important points; the deductions were somewhat at variance with former teachings, but an exposition of the facts would elicit useful information from others who had conducted similar inquiries. In the meantime, he would simply observe, that the experiments proved, that with the exception of some anomalies which presented themselves in clay soils, tending to confirm the doubts which had been expressed, the extension of under-drainage throughout the wet lands of the kingdom, of all descriptions, must very materially increase the discharge of water to the main outfalls, during the winter months.

Mr. GRANTHAM remarked, that in drawing up the Paper which he had presented to the Institution, he thought, in the first instance, that it would have been useful to have classified the different descriptions of rivers in England, in order that the special mode of treatment of each river might have been discussed. He, however, considered subsequently, that such a mode of dealing with the subject would be too complicated, and would not, perhaps, be so intelligible as the plan he had afterwards adopted, of confining his observations to those rivers which ran through level, or fen districts, and those which ran through upland districts. He had endeavoured, in the Paper, to lay down the general principles which should, in his opinion, be adopted, for carrying out a proper system of arterial drainage and outfalls, and upon the subject of the drainage of the fen districts, he had referred to the Paper of Sir John Rennie, on the Ancholme Drainage. He had mentioned the adoption of catchwater drains; he had dwelt upon the mode in which main drainage should be carried out in connection with tidal rivers, and the level at which the cills of gates and sluices should be placed; and he had called special attention to the principle, that the main drains should become the receptacles of drainage waters when the locks, or gates were shut. The next question he had attempted to deal with, was that of the drainage of internal, or upland rivers, and the mode in which the channels should be straightened, so that the waters should be confined and used in the most economical manner for all purposes, both town and agricultural. He had pointed out, that there should be a power to irrigate adjoining lands, and he had alluded to the mode in which drains of that kind, with great velocity, should be formed, suggesting, that the velocity should be checked by steps, or overfalls at certain places, and that the velocity of the water and the

slopes of the drains should be regulated according to the necessity of the soil. That plan had been successfully adopted in the Hainault Forest drains, to the extent of 3 miles, or 4 miles; the water never overflowed the banks, and the works fully answered all the purposes intended. If he had been allowed to do so by the Commissioners of the Woods and Forests, he had intended to take gaugings at each of the overfalls, in order to ascertain the exact quantity of water which was discharged over the area drained between one overfall and another, and to have kept a rain gauge on the estate, so as to ascertain, as nearly as possible, the amount of rainfall, and compare it with the actual quantity of drainage and the evaporation from the area of 2,000 acres. He admitted the importance of drainage into tidal rivers; but at the same time, he thought the discussion had digressed too far into the question of the management of tidal harbours. He had referred to the treatment of some of the Indian rivers, which required works for irrigation and navigation, upon a scale infinitely more extensive than those in this country, and afforded excellent lessons in the mode of training rivers which brought down large quantities of sand, stone, and sediment in times of flood, requiring for their control the greatest skill and care on the part of the Engineer. He had also referred to the best authorities upon the mode of drainage pursued in other countries; and had pointed to the works of Paul Frisi and others, as they afforded a great deal of information, which would be found most valuable. He had also recommended those interested in the subject, to consult the published work of Captain Baird Smith, R.E., on the drainage of Northern Italy and the Madras Presidency. The latter authority had taken great pains with the subject, and being wholly uncontrolled in his investigations, had collected the best possible information.

The Paper did not allude to any particular legislative measure by which drainages should be regulated. It was limited to a statement of the fact, that the want of legislation on the subject was a great impediment in carrying out inland drainage upon a large scale. Mr. Grantham had personally experienced that want, in which he had been confirmed by those who had been largely engaged in drainage operations. The managers of large estates, and landowners themselves, would be glad to have some power of enabling them to effect arterial drainages and outfalls. It was, no doubt, a difficult question to decide upon the nature of the remedy; there were numerous instances in which it would appear desirable to bring some legislative powers to bear, but in any case, he certainly should not put the matter into the hands of special commissioners, for fear of the creation of such a body as that of the General Board of Health, which had done so much mischief in the drainage of towns. The only power he desired, would be

a permissive power; and he thought the Inclosure Commission presented, as nearly as possible, a model of that which was required for dealing with the subject of general drainage. The agricultural interest of the country was, he believed, very well satisfied, upon the whole, with the manner in which the Inclosure Commissioners had exercised the powers intrusted to them, and such great benefit had resulted from their proceedings, that scarcely a dissentient voice had been raised against them. The Engineers of this country need not be under any apprehension, if work of this description was put into their hands. The Commission did not pretend to control; it had merely a permissive power, and that was all that was required in drainage. It was a mistake to suppose, that he wished for any board, or commission to exercise a controlling power, or that he was an advocate for centralisation in matters of this kind, opposed, as he had always been to the application of that system to agriculture, or any other branch of industry: at the present day, such a proposition would give umbrage to the whole country. The Institution of Civil Engineers, composed, as it was, of practical men, was the body by which the question could be best discussed, and the difficulties best considered; and their opinions would be found of great value and assistance, should the Legislature entertain any proposal upon the subject. There could be no doubt, that in the drainages of large districts, such as the fens, improvements could only be carried out under the authority of special legislative enactment, and he considered the Bill introduced in 1853, by the Earl of Carlisle, as the best model for adoption.

Some rather discouraging remarks had been made with reference to pipe drainage, which was a question largely mixed up with arterial drainage. Although the Paper was purely agricultural, he had determined to bring it before the Institution, because, at the present moment, Engineering was the science which could best come to the assistance of agriculture. The adoption of a regular system of arterial drainage and outfalls would give immense employment to Engineers, and would open out a new and highly interesting field of occupation. Speaking from his own experience, there were few branches of the profession which called forth so much interest as that under discussion. He agreed, that under particular circumstances, drainage might be carried to too great a depth, but no general principle applicable to all cases could, in that respect, be laid down: in some cases, a drainage of 5 feet would be beneficial, whilst in another it would be productive of disastrous results. He had introduced the Irish drainage as an example of what might be effected, under a combined and uniform system, to relieve large areas of land injured to an enormous extent, and in many instances, rendered totally valueless by pent-

up and stagnant waters. The grand defect in the system was, that there was no provision for maintaining these costly works.

Mr. BIDDER,—President,—said, that having been called to the Chair since the opening of the discussion, his present position precluded him from expressing, at any great length, his views upon the question, his duty now being rather to watch the discussion than to take part in it. He would merely remark, that some of the worst bars on the coast had no connection at all with the outfall of rivers; and that there were cases in which the land water absolutely obstructed and diminished the quantity of the scour. He fully concurred in the opinion, that dogmatic draining was utterly impracticable. The level of the land, the nature of the soil, and a variety of other circumstances required to be taken into consideration, in determining the depth to which the drainage should be carried. The late Mr. Tycho Wing, who had devoted much attention to drainage, had ascertained, that for the fens, the best level was 2 feet 6 inches below the surface. When the drains were deeper, the crops deteriorated, and when they were higher, the effect was equally injurious. He would also remark, that there were two kinds of drainage to be considered: on the one hand, drainage wholly independent of, and unconnected with, tidal rivers; and on the other hand, drainage which must flow into rivers affected by tidal action, when the question became dependent upon their levels being 2 feet, or 3 feet higher, or lower. For those reasons, he did not consider the discussion to have deviated from the scope of this interesting Paper. The subject, however, was by no means exhausted, and he hoped, that at some future time, it would again be brought under consideration. Further communications from those who had directed their attention to the subject would lead to discussions of the highest importance to the profession.

Mr. J. HODGSON JONES,—through the Secretary,—confirmed the observation which had been made relative to the obstruction of drainage by the farmers, in some parts of the fens, during summer. The fact was undoubtedly correct, but in his opinion, it did not militate against the general argument, that deep drainage should be regarded as the rule, and shallow drainage as the exception. As the name of the late Mr. Tycho Wing had been mentioned, as an authority for fixing the maximum depth to be given to drains in the fen districts at 2 feet 6 inches, it was important to state, that in the latter years of his life, his views upon that point had been considerably modified. Indeed, the question of prospectively lowering the water level in those districts had been anxiously discussed by him: in many instances he recognised the necessity of increasing the depth to 4 feet, and he became fully impressed with the advantages to be obtained by deep draining.

In the fen districts, under the top soil, clay, loam, and occasional veins of sand were generally found, so that the drainage most beneficial to those districts would, in many cases, be somewhat similar in character to that for clay soils, provided that, in times of drought, the water levels in the ditches could be raised. Such a provision was rendered necessary by the peculiar character of the fen surface-soil, and was, in some cases, effected by a supply for the cattle being led into the ditches from an independent source.

Mr. HAWKSLEY complained, that his views upon the state of drainage in England had been misconceived. So far from thinking, that it was in a disastrous condition, and that it had been carried out to too great extent, he thought, on the contrary, that drainage had not been carried far enough. His objection extended only to the great depth which had, in many cases, been given to drains, whereby the surface of the land had become too dry for green crops, requiring a large amount of moisture. Many crops, such as turnips, beet-root, and mangold-wurzle, which yielded from 20 tons to 40 tons per acre, and consisted of about 90 per cent. of water, could not be raised, unless the roots of the plants penetrated sufficiently deep to reach an ample supply of moisture. In Worcestershire, in the north of England, and also in the south of England, by draining to too great a depth, the ground cracked, and it became quite impossible to raise any other than cereal crops; the produce even of those crops, if the drought was continuous, was sensibly diminished. In those instances, the drainage had been injurious; not perhaps invariably, because every fifth, or sixth year, there might be a great deal of rain. He protested, therefore, against any system of drainage, founded upon general theories of a fallacious character, without reference to the chemical and the natural circumstances of each particular case. When drainage was carried out to a moderate depth, and the drains were made more numerous instead of so far apart, he was the greatest advocate for it, feeling convinced, from his personal observation and experience in England, Scotland, and Ireland, as well as on the Continent, that the effect of arterial drainage was to remove the land several degrees further towards the south; and that, if judiciously carried out, it would tend, very materially, to improve cultivation.

In opposition to his views as to the imprudence of intrusting the power of dealing with lands and watercourses to Government authorities, one of the most favourable cases of Government interference had been adduced. But it was hardly fair to call the Inclosure Commission, a Government commission; for the action of that body was as free as the action of the Judges of the Law Courts, and was independent of the Government for the time being. The object of the Inclosure Commission was simply to dissolve partnerships, which had become disadvantageous and

unsatisfactory to all the parties concerned. But the duty of a Government commission appointed to deal with rivers, estates, buildings, mills, or other property, would be the very reverse, the object then being to compose partnerships, and to compel people to concur in some act to which, probably, they had the utmost objection. Such a mode of action, whenever it had been attempted, had always led to great opposition in this country. The proper tribunal was either Parliament itself, or a commission similar to that of Henry VIII., which had, upon the whole, worked well, and had proved exceedingly serviceable, where it had not been suffered to fall into desuetude.

He would now briefly refer to the amount of rainfall and the quantity of water flowing therefrom into the rivers. In one of the largest cases with which he was acquainted, the Liverpool Waterworks, he had ascertained, that ten years ago, the total rainfall of that district of Lancashire was from 54 inches to 56 inches, a quantity which was unknown in the neighbourhood of London. The whole of the water flowing down the brooks and streams passed over gauges, and a register was regularly kept every four hours, during two years, which proved to be years of more than average rainfall. It was then found, that all the water which fell, was discharged to within 10 inches; and that whilst the average quantity of rain water upon that area of 10,000 acres was about 25,000,000, or 26,000,000 gallons per day, not more than about 1,500,000 gallons came out by the springs. He had also gauged the water in more southerly districts, where about 16 inches of rainfall out of an average of 22 inches was evaporated, leaving only 6 inches to be disposed of in other ways. Such had been the case with the River Thames, a result which, in his opinion, explained, in some degree, the foul state of that river during the last few years.

On the subject of town drainage, he would simply correct the general but erroneous impression which prevailed, that because the matter which went into the sewers was exceedingly valuable as a fertilising agent, therefore, that which came out of them must be equally valuable. Many persons seemed yet to be ignorant of the destructive effects of oxygen, on the manurial elements contained in sewage water.

Mr. Bidder,—President,—deprecated the introduction of so very important a subject as the sewage of towns into a discussion upon arterial drainage, more especially, as it had not been alluded to in the Paper. The observations of the last speaker would have the full weight to which they were entitled from his position as an Hydraulic Engineer, and the philosophical and discriminating manner in which he had examined the subject; it was only to be regretted, that he did not embody them in a Paper, for the benefit of

the Institution. Some remarks, quite true in themselves, however, with regard to the scour of rivers, the President could not allow to pass, without alluding to the limits to which their application extended. It had been stated, that the effects of land water and scour should be added to the ebb tide. Those remarks were applicable to a harbour with a large estuary behind it, which was emptied at every tide, and a river falling into it over a weir; in that case, undoubtedly, the land water was added to the ebb. It should not, however, be forgotten, that it was as essential to have a vigorous flow as well as a vigorous ebb. In the case of the River Thames, it was well known, that high water occurred at Gravesend one hour and a half sooner than at London Bridge; and that at Southend, at the mouth of the river, it was flood two hours, or three hours earlier than at London Bridge; at Richmond, low water was, probably, coincident with high water at the mouth of the river. Between Richmond and Teddington Lock, over which the land water passed during the whole time of the flood tide, the current in one portion of the river would be flowing up, at the same time that, in another portion, it was running down. In that case he did not say the land water was ineffective, but he said it was a question for investigation. At low water, the entire current would, for the moment, flow in one direction; on the ebb tide, it would be precisely the converse. How far these conditions were consistent with the idea, that the whole of the land water was added to the ebb, was a subject for investigation and discussion, and he hoped it would, on a future occasion, receive the attention which its importance deserved. It had also been stated, that the formation of bars was due to the deposition of matter brought down by the rivers to their mouths. As far as his own observation went, he doubted whether one single particle brought down by a river was deposited in the shape of a bar; and whether the bar, in some cases, was not a simple continuation of the adjoining beach. At Yarmouth, the bar was composed of the shingle and sand adjoining: whereas in rivers where there was no analogous coast, as at Dartmouth and Falmouth, there were no bars whatever. In Holland, and in the estuary of the Lynn Deeps, the whole substratum of the reclaimed land was formed from sea sand, and the flocculent matter deposited above, constituted the fertilising portion.

The subject of Government interference with the details of the drainage of land in this country, had been so often alluded to in the discussion, that although foreign to the objects of the Institution, he could no longer refrain from expressing his views upon the subject. As to existing rights, all must agree, that the remedy for the preservation of streams in a proper and healthy condition, ought to be sharp, speedy, and economical. That result had not

yet been attained; for the Courts of Law, whether acting by injunction, or otherwise, were cumbrous, expensive and unsatisfactory tribunals. Neither judge nor counsel had any knowledge of engineering science; the arguments adduced were often, therefore, as ridiculous as could well be conceived. For cases of this nature, a special court was necessary, presided over by a judge conversant with mechanical laws. He was decidedly opposed to any compulsory interference with private rights. It behoved Parliament to be very cautious before granting such power to any board, except upon the clearest evidence and upon public grounds. Railway, Dock, Canal, and Road Companies were not permitted to deal compulsorily with a single acre of land, until they had proved they were about to confer some benefit upon the public.

Great inroads had already been attempted in this direction, for at the end of the last Session of Parliament, the Government passed an Act, vesting in the hands of the Secretary of State, the power to deal with certain private property, or in other words, delegating that power to the nominee of some Government Board, for the Secretary of State could not, personally, investigate all the necessary details.

He would conclude his remarks by reading an extract upon this subject, from a pamphlet written by the great orator, Edmund Burke:—

"The clearest line of distinction which I would draw, whilst I had any chalk to draw my line, would be this:—that the State ought to confine itself to what regards the State, or the creatures of the State, namely, the exterior establishment of its religion, its magistracy, its revenue, its military force by sea and land, the corporations that owe their existence to its fiat;—in a word, to everything that is truly and properly public; to the public peace, to the public safety, to the public order, to the public prosperity. Statesmen who know themselves, will, with the dignity which belongs to wisdom, proceed only in this, the superior orb. Whatever remains will, in a manner, provide for itself." Speaking of the tendency of French politicians to fail in discriminating between what belonged to laws and what manners alone could regulate, he observed:—"The once mighty State, which was nearest to us locally, nearest to us in every way, and whose ruins threaten to fall upon our heads, is a strong instance of this error. I can never quote France without a foreboding sigh. The hand of authority was seen in everything and every place. All, therefore, that happened amiss in the course even of domestic affairs was attributed to the Government, and, as it always happens in this kind of officious universal interference, what began in odious power ended always, I may say, without an exception, in contemptible imbecility."

December 6, 1859.

JOSEPH LOCKE, M.P., President,
in the Chair.

The following Candidates were balloted for and duly elected :—Arthur Charles Crosse, William Henry Purdon, and Walmsley Stanley, jun., as Members; John Aird, jun., Edward Cottam, William Henry Richards Curll, James Benjamin Dunn, John Evans, Joseph Fisher, jun., Fleeming Jenkin, James Kimber, John Herbert Latham, John Folliott Stokes, Joseph Taylor, and John Thwaites, as Associates.

The discussion upon the Paper, No. 1,005, "On Arterial Drainage and Outfalls," by Mr. R. B. Grantham, occupied the whole evening, to the exclusion of any other subject.

ANNUAL GENERAL MEETING.

December 13, 1859.

JOSEPH LOCKE, M.P., President, in the Chair.

Messrs. W. B. Bray, W. Haywood, and A. C. Hobbs, were requested to act as Scrutineers of the Ballot, for the election of the President, Vice-Presidents, and other Members and Associates of Council.

The list of the attendances of the Members of Council for the past year was read, and the Ballot was commenced; the balloting-papers being sent for examination, at intervals of fifteen minutes, in order to expedite the labours of the Scrutineers.

The Annual Report of the Council, on the proceedings of the Institution during the past year, was read.

Resolved,—That the Report of the Council be received and approved; and that it be referred to the Council, to be printed and circulated with the Minutes of Proceedings, in the usual manner.

Resolved,—That the thanks of the Institution are due, and are presented to Messrs. Pole and Maudslay, for the readiness with which they undertook the office of Auditors of Accounts, and for the clear statement they have laid before the Meeting; and that Messrs. Maudslay and Kingsbury be requested to undertake the office of Auditors for the ensuing year.

The Telford and Watt Medals, and the Council and Manby Premiums, which had been awarded, were presented.

Resolved,—That the thanks of the Institution are justly due, and are presented to the Vice-Presidents and other Members of the Council, for their co-operation with the President, their constant attendance at the Meetings, and their zeal on behalf of the Institution.

Mr. Bidder, V.P., returned thanks.

Resolved unanimously,—That the cordial thanks of the Meeting be given to Mr. Joseph Locke, M.P., President, for his strenuous efforts in the interests of the Institution, for his extraordinary

attention to the duties of his office, and for the urbanity he has at all times displayed in the Chair.

Mr. Locke, M.P., returned thanks.

Resolved unanimously,—That the cordial thanks of the Meeting be given to Mr. Charles Manby, the Secretary, and to Mr. James Forrest, the Assistant Secretary, for their constant zeal and devotion to the interests of the Institution, the ability displayed by them in the execution of their duties, and their attention to the individual wishes of the Members.

Mr. Manby and Mr. Forrest returned thanks.

The Ballot having been open more than an hour, the Scrutineers, after examining the papers, announced that the following gentlemen were duly elected to fill the several offices in the Council for the ensuing year:—

President.

GEORGE P. BIDDER.

Vice-Presidents.

John Fowler.	John Hawkshaw, F.R.S.
Charles H. Gregory.	John R. M'Clean.

OTHER MEMBERS OF COUNCIL.

Members.

Sir W.G. Armstrong, C.B., F.R.S.	George W. Hemans.
Joseph Cubitt.	John Murray.
John E. Errington.	J. Scott Russell, F.R.S.
Thomas E. Harrison.	George Robert Stephenson.
Thomas Hawksley.	Joseph Whitworth, F.R.S.

Associates.

William Bird.	Captain Mark Huish.

Resolved,—That the thanks of the Meeting be given to Messrs. Bray, Haywood, and Hobbs, the Scrutineers, for the promptitude and efficiency with which they have performed the duties of their office, and that the ballot-papers be destroyed.

ANNUAL REPORT.

SESSION 1859-60.

IT has hitherto been the practice to give, in the Annual Reports, a succinct account of some of the engineering works in progress, or which have been completed during the preceding twelve months; and even, in exceptional cases, to allude to remarkable projects. From this custom it is not intended to depart on the present occasion; although the time is approaching, when the Report may be restricted to the affairs and the state of the Institution. If it is observed, that foreign undertakings occupy a principal place in the present summary, it may be partly explained by the fact, that a great number of the Members and Associates are employed abroad; while of those who remain in the United Kingdom, a large proportion are similarly engaged, in connection with important works, in course of execution, in all parts of the world. Every year extends the field of operations for the exercise of professional skill; and wherever civilisation and commerce may reach, there also will arise the necessity for the labours of the Engineer.

Commencing at home, it may be stated, in reference to the Main Drainage of the Metropolis, that the first contract for these works was let, early in the present year, to Mr. Moxon for £152,430. This portion is called the 'Northern High Level Sewer,' and is about nine miles in length, extending from Hampstead to the River Lea. The heaviest part of this contract, involving works to the amount of £80,000, has been already completed. The next contract was, for the 'Southern High Level Sewer,' extending from Clapham to Deptford Creek, and being, with its branches, about nine miles and a half in length. This contract was taken, last July, by Messrs. Helling and Yeoman, for £217,000; and the works are progressing vigorously in several localities. The third contract, for the 'Southern Outfall Sewer,' from Deptford Creek, under Woolwich, to Erith Marshes, about seven miles and a half in length, will be let immediately. Several other important works would have been

in a much more forward state, but for the strike in the building trades.

Designs and tenders for pumping engines, of 500 nominal H.P., intended to raise the sewage into the Southern Outfall Sewer, at Deptford Creek, were received, from a selected number of engine manufacturers. These were reported upon, in June last, by a Committee, composed of Mr. Robert Stephenson, (our late President,) Mr. Joshua Field, (Past-President Inst. C.E.,) Mr. John Penn, (M. Inst. C.E.,) Mr. G. P. Bidder, (V.P. Inst. C.E.,) Mr. T. Hawksley, (M. Inst. C.E.,) and Mr. J. W. Bazalgette, (M. Inst. C.E.); when new designs for engines and pumps, such as were recommended by the Committee, were ordered to be prepared by Mr. Hawksley, and are now ready for submitting to the manufacturers.

With a view to the purification of the waters of the Thames during the summer months, 4,300 tons of lime, 500 tons of chloride of lime, and 56 tons of carbolic acid, were used in deodorising the sewage; and an important Report upon this subject has been obtained from Drs. Hofmann and Frankland.[1] A new bridge for the approach to the Victoria Park is being built over the Limehouse Cut, at a cost of £5,000. A portion of the main drainage sewer is being constructed in the Uxbridge Road, at a cost of about £10,000; and works of improvement, cleansing, and repairs, to a large extent, have been carried on, in connection with the main sewers of the Metropolis, during the past year. A temporary pumping engine, of 100 H.P., is being erected by Mr. R. Daglish, jun., (Assoc. Inst. C.E.,) at the mouth of the Earl Sewer; and that main sewer is about to be diverted and reconstructed, with a view to the immediate relief of the southern low-level districts, from floods, pending the construction of the main drainage works.

The Metropolitan Board of Works is now fairly at work, with ample funds at their command; and the public will expect, within a short period, evidence of improvement commensurate with the expense incurred.

The possible effects of these works on the River Thames, in concentrating the sewage matter to two spots, and the abstraction of a large body of water from the higher reaches of the river, for the supply of the Metropolis, have been much discussed; and it is evident, that the question must soon be carefully considered, in order to determine what remedial measures, if any, are necessary, to preserve the régime of the river.

The extension of the railway communications of the Metropolis, as well as bringing the termini of the existing lines nearer to the

[1] *Vide* "Metropolitan Board of Works.—Report on the Deodorisation of Sewage. By Dr. Hofmann, F.R.S., and Dr. Frankland, F.R.S. 12 August, 1859." No. 24.

most densely populated districts, has latterly received much attention. The contracts for the works on the Metropolitan Railway, under the direction of Mr. Fowler, (M. Inst. C.E.,) have just been let, and will be immediately proceeded with. The line commences by a junction with the Great Western Railway, and terminates at Victoria Street, opposite to Farringdon Street, having a branch to the Great Northern Railway. It is to be constructed on the mixed-gauge system, and will be completed, it is expected, in less than two years from the present time. A considerable portion of the line will be open work, with retaining walls; but some parts will necessarily be in tunnel. The tractive power intended to be employed is peculiar. It is proposed to condense the steam used in the locomotive engine, and to reduce the size of the ordinary fire box, so as to have as little inconvenience as possible from the steam, and from the products of combustion. This undertaking is looked upon with much interest, not only by the profession, on account of the nature of the works, but also by the public; for, if successful, it may be expected to introduce a complete system of metropolitan sub-railways.

The Victoria Station and Pimlico Railway, also under Mr. Fowler, intended to connect the railways on the south side of the river, near to Battersea, with a station in the heart of Belgravia, and within three-quarters of a mile of the Houses of Parliament, is making rapid progress, and will be opened, it is believed, in the ensuing summer. One of the principal works is the bridge over the Thames,—the first, for railway purposes, yet built in the Metropolis. It will consist of four wrought-iron arches, with abutments and land arches, and is so far advanced, that there is every reason to think it will be completed, within twelve months from the time of laying the first stone.

In the last Session of Parliament, a great number of Bills were promoted, having a similar object to those last mentioned. The Charing Cross Railway, for which an Act was recently obtained, has been brought forward, mainly, with the view of affording a west-end terminus to the South Eastern Railway. It will involve the construction of a bridge across the Thames, where the present Suspension Bridge now stands, and the terminal station is intended to be formed on the site of Hungerford Market. The proposed bridge will consist of eight openings, each of 154 feet, which will be spanned by wrought-iron girders. It will be of sufficient width to carry four lines of way, and there will also be two public footways, one on each side of the bridge. The design for this structure has received the approval of the Conservators of the River Thames and of the Admiralty; and it is expected, that the works, which are under the direction of Mr. Hawkshaw, (V.P. Inst. C.E.,) will be commenced immediately.

The West London Railway Extension will connect the North Western and the Great Western, with the South Western, and the Brighton and South Coast Railways; thus completing the communication between the lines north and south of the River Thames, and enabling passengers and goods to pass through the Metropolis without the delay, inconvenience, and expense of a change of conveyance. The line will be about 3 miles in length. It commences at the Kensington Basin, follows, nearly, the course of the canal, crosses the river at Battersea, and joins the South Western Railway at Falcon Bridge, near to which it also effects a junction with the Crystal Palace Line, and with the Victoria Station and Pimlico Railway.

A branch from Kingston to Twickenham, on the South Western (Windsor) Line, and improved junctions at Barnes and Kew, will place the populous district of Kingston, in communication with the northern and eastern suburbs of the Metropolis.

From the number of new projects again brought forward for the coming Session, it is evident, that great interest continues to be felt on the subject of improved metropolitan railway communications; several of them promise to be important, in giving increased accommodation to the public, as well as improving the lines of which they will form branches.

Among the lines of railway recently completed in England, may be mentioned the Portsmouth, and the Shrewsbury and Crewe Railways, both executed under Mr. J. Locke, (President Inst. C.E.,) and Mr. J. E. Errington, (M. Inst. C.E.) The main object of the Portsmouth Railway was to shorten the distance between the important naval depôt situated at that place, and the Metropolis. Its length is rather more than 32 miles, and the distance is reduced by it from 94 miles to 73 miles. The principal work upon the line was a cutting at Haslemere, upwards of 80 feet in depth for a quarter of mile in length, and containing upwards of half a million cubic yards of material. This was executed through the Wealden clay, and it was found, that a deep intercepting drain on the west side proved very beneficial in preventing slips. The Shrewsbury and Crewe Railway, which is about 32 miles in length, and passes over the Cheshire Plains, connects the manufacturing districts of Lancashire and Yorkshire with North Wales. The chief point of interest in the works, was the manner in which the heavy Cheshire clay was successfully dealt with, by observing great care in the drainage.

In the Lake district, the Coniston Railway has recently been completed, as well as branch lines from the South Staffordshire Railway, to Cannock, Norton, Tipton, and Darleston, under Mr. J. R. McClean, (V.P. Inst. C.E.,) and Mr. F. C. Stileman, (M. Inst. C.E.)

The Severn Valley Railway, under Mr. Fowler, is intended to

connect the Oxford, Worcester, and Wolverhampton Railway, near Kidderminster, with Shrewsbury, and its system of railways. The works have been commenced about twelve months, and will be completed, it is expected, next year. The line is 40 miles in length, and runs along the valley of the River Severn, taking the rising ground at a sufficient level to keep it well above the waters of the river. There will be two tunnels through the new red sandstone, which formation prevails for the greater part of the line. The bridges will be numerous, including one of cast iron over the Severn, at Arley, in a single arch of 200 feet span and 20 feet rise. At Hagley, about nine miles from Stourport, a very large natural slip occurs, in the clay of the coal measures. This slip is believed to be still slowly progressing, but no exact observations have recently been made. It has forced out of its natural course, the bed of the river, which now runs in a curve round the base. An attempt to take the railway cutting through it has proved so difficult, from the treacherous character of the soil, that a deviation of the line at that point has been determined upon, in order to lighten the works.

The works on the Extension Lines to the West of England, in connection with the South Western system, are being vigorously prosecuted by Mr. Brassey, (Assoc. Inst. C.E.,) under the direction of Mr. Errington. The Salisbury and Yeovil Railway has been opened to Gillingham, a distance of about 20 miles, being as far as the operations at the heavy tunnel there, at present permits. It is expected, that these lines will be completed throughout, to Exeter, early in the ensuing summer.

Passing now to hydraulic works, it may be stated, that considerable progress has been made with the extension works of the Grand Surrey Docks, the trade of which, though consisting almost entirely of timber, has hitherto been much restricted, by the limited dimensions of the entrance lock, the insufficient depth of water over the cills, the inadequate water and yard accommodation for timber and deals, and the want of access to the high road. The new works comprise a timber pond of 15½ acres, an inner dock of 12 acres, and a basin of nearly 3 acres, connected with the former by a pair of gates, and to the upper portion of the old dock by another pair of gates, and communicating with the River Thames by an entrance, 250 feet in length between the gates, and 50 feet in width. The total area of water, including the additions, amounts to about 50 acres. The depth of water over the cills of the outer and upper gates, is 9 feet at Trinity low-water, or 27 feet at Trinity high-water, and over the cills of the two inner gates it is 1 foot less. The basin and inner dock have each a depth of 26 feet of water at Trinity high-water mark, and the

latter is connected with the new timber pond by an opening, crossed by a bridge 30 feet in span. This timber pond is connected with the old pond in a similar manner, so that the old and the new systems are in efficient communication. The side walls of the lock and basin are of brickwork, backed with concrete, and the platforms of the inverts and gates, are of similar construction. The gates are cellular, and are built of iron boiler-plates. The entrance wharfing, outside the lower gates, is composed of cast-iron piling, with concrete behind; the upper part, above low-water mark, being of creosoted timber, also backed with concrete. The new works include a swing bridge across the entrance, a commodious communication with the Deptford Road, and considerable additions to the deal yards. They were designed by Messrs. Bidder and Joseph Jennings, and are being executed, under their superintendence, by the contractors, Messrs. George Baker and Sons, Mr. Kingsbury, (Assoc. Inst. C.E.,) taking the immediate direction of the works. The gates are being made and erected by Messrs. Robert Stephenson and Co., of Newcastle-upon-Tyne.

During the past year, several dock and harbour works have been completed, under the direction of Mr. Abernethy, (M. Inst. C.E.) The new docks at Swansea have an area of 17 acres, with an entrance 70 feet in width, and a lock 300 feet long and 60 feet wide, having a depth of water of 25 feet over the cill. These docks are capable of accommodating the largest class of shipping, and have on the quays, drops for the shipment of coal, which, together with the machinery for the bridges, gates, and cranes, are worked by hydraulic power, supplied by engines of 130 H.P., with accumulators at different points of the dock. At Newport, a dock, having an area of 8 acres, with an entrance 60 feet in width, has been opened. Hydraulic lifts have been provided, by which the waggons are raised from the level of the quays, to the necessary height for discharging the coal into the holds of the vessels. The five hoists are capable of loading 30,000 tons of coal per week. All the dock appurtenances are worked by hydraulic apparatus, supplied by an engine of 70 H.P.

At Silloth, on the Solway Frith, a pier has been completed, for a length of 1,000 feet, into deep water, so as to accommodate steamers at all times of the tide. The rails are laid, to the termination of the pier, at a level of 50 feet above the bed of the sea. In connection with the pier, a dock has been completed, of 4 acres in area, with an entrance 60 feet in width, and a depth of 25 feet over the cill; the sea channel being excavated to the same depth. The hydraulic lifts invented by Sir William Armstrong, (M. Inst. C.E.,) have, as in the other cases named, also been adopted, for the shipment of coal, and for working the dock gates, cranes, and appurtenances.

At Blyth, in Northumberland, a pier and breakwater have been completed, 4,500 feet in length, for the shelter of the harbour; and a sea channel, of the same length, has been dredged and excavated, for the admission of the larger class of coal vessels.

At Penarth, near Cardiff, the River Ely, at its confluence with the Bristol Channel, and for some distance inland, has been converted into a tidal harbour, by regulating, embanking, and improving its course. The slopes have been protected by stone pitching; and accommodation has been provided, by the erection of staiths and wharves, for shipping coals and for commercial purposes. A railway, 6 miles in length, connects the harbour with the Taff Vale Line. A dock is now in course of construction, in connection with the harbour. It will have an area of about 15 acres, and there will be an entrance basin of about 3 acres. These works are under the joint charge of Mr. Hawkshaw, and Mr. S. Dobson, (M. Inst. C.E.)

At Southampton, Mr. Alfred Giles, (M. Inst. C.E.,) has just completed the deepening and enlarging of the inner dock, and the construction of a new entrance 56 feet wide, with a depth of water over the cill of 28 feet at high-water spring-tides, a swing bridge spanning the entrance.

At Southport, Mr. Brunlees, (M. Inst. C.E.,) is constructing a pier, three-quarters of a mile in length, composed of cast-iron piles and columns, carrying wrought-iron lattice girders.

The Norfolk Estuary works, for completing the banks of the River Ouse at the entrance to the Wash, and for reclaiming considerable tracts of land from the sea, are in active progress, under Sir John Rennie, (Past-President Inst. C.E.), and Mr. Forster, (M. Inst. C.E.); whilst at Eastbourne, Sussex, new waterworks have been completed by Messrs. McClean and Stileman.

In the Report of a former year,[1] allusion was made to the plan for supplying the city of Glasgow with water, from Loch Katrine; which was being carried out under Mr. J. F. Bateman, (M. Inst. C. E.) This great work is now nearly completed, and was formally inaugurated by Her Majesty Queen Victoria, in the month of October last. The storage provided for the water is sufficient for 50,000,000 gallons per day. It is conveyed to its destination by an aqueduct 34 miles in length, comprising seventy tunnels 8 feet in diameter, nine of which are of considerable length, through rock of the most obdurate description. There are also twenty-five important iron and masonry aqueducts, over rivers and ravines, some of them being of considerable height. This work, which has afforded employment to about three thousand persons

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xvii., pp. 76, 77.

in the locality, has been executed through a district of the wildest and most inaccessible description. The time occupied in the execution of the works has been within three years and a half, and the cost has been £630,000, about 10 per cent. in excess of the Parliamentary estimate, after allowing for some additional works.

In the West of Scotland, the Castle Douglas and Dumfries Railway, starting by a junction at the latter place with the Glasgow and South Western Line, has recently been opened. Its length is about 20 miles. From Castle Douglas, the Portpatrick Railway is being actively pushed forward, with the view of completing the communication with Ireland by the short sea passage, viâ Portpatrick and Donaghadee. The line is about 61 miles in length, and it is expected, that the works will be completed early next autumn. There are several large viaducts in progress of construction. One over Loch Ken, consists of three openings, each 130 feet, spanned by bow-string wrought-iron girders, and two smaller openings at each end. The two principal piers are above the water line; the foundations having been laid on cast-iron tubes, at a depth of 33 feet and 38 feet below the level of the water. There are masonry viaducts over the Blackwater of Dee, the Little Fleet Water, the Big Water of Fleet, and the River Luce, varying from 40 feet to 75 feet in height. Over the River Cue there is a viaduct of five openings, each 80 feet, spanned by wrought-iron plate girders, resting on timber piers. It is intended to open the line to Stranraer during the ensuing autumn, and in the following year to Portpatrick, by which time it is believed the Government harbour there will be completed. The works on the Portpatrick Railway are being executed under the direction of Messrs. B. and E. Blyth, (MM. Inst. C.E.)

Considerable progress has been made, during the past year, in the development of the railway system of Ireland. The lines from Longford to Sligo, Athenry to Tuam, Newry to Armagh and to Warren Point, and Dungannon to Omagh, under Mr. Hemans, (M. Inst. C.E.,) comprise some considerable tunnels and other large works. The lines from Athlone to Roscommon, and thence to Castlereagh and Castlebar, (ultimately to be extended to Westport, Ballina, and Boyle,) under Mr. Fowler and Mr. F. Barry, (M. Inst. C.E.,) and from Athlone to Tullamore, Killarney to Tralee, Mallow to Fermoy, under Mr. Le Fanu, (M. Inst. C.E.,) with some others of less importance, have been prosecuted at the same time. The connection of the central town of Longford with the seaport of Sligo, a distance of about 60 miles, will give an important extension to the Midland Great Western Railway, which will then have termini at Galway, Sligo, and Dublin, with lines down to the water's edge, at each of those three harbours,

thus embracing a system of railways, upwards of 300 miles in length, in the most central position in Ireland.

The most desirable port on the Western Coast of Ireland, for the station of the Atlantic steamers to America, was, for some time, a subject of discussion. Ultimately, Galway was selected for that purpose, and subsidies have since been guaranteed by England and Newfoundland, to the amount of £91,000 per annum, for the fortnightly conveyance of mails and passengers both ways. A considerable saving of time, in the transit between the United States and Great Britain, is to be expected from the adoption of the Galway route; it also possesses an equally powerful recommendation in the fact, that the difficult and dangerous coast navigation either on the north, or the south shores of Ireland, towards the Mersey, will be avoided.

It may be mentioned, as an element in the advancing prosperity of Irish Railways, that the two principal Companies, the Midland Great Western and the Great Southern and Western, have, after several years of loss, by competition, agreed to submit the whole district occupied by their lines and canals to the consideration of arbitrators, who will allot to each Company their proper sphere of action, so as to remove all ruinous competition. As this arrangement embraces the railway system of more than two-thirds of the whole country, it is one of great importance.

At Londonderry, a bridge is being built, of which Mr. Hawkshaw is the Engineer, for the double purpose of carrying a railway and a roadway over the River Foyle. In this instance, the railway is placed beneath the roadway. At the High Level Bridge, Newcastle, the reverse is the case. The Londonderry Bridge will consist of six main openings, each 120 feet in span, of a centre swing bridge, with two openings of 45 feet span each, and of two land openings, at each end, of about 60 feet span. The piers are being formed by sinking cylinders in the bed of the river, and the openings will be spanned by wrought-iron girders. By means of this bridge, a junction will be effected between the Londonderry and Enniskillen, and the Londonderry and Coleraine Railways, which, at present, have their termini on opposite banks of the river.

The only other works of note in Ireland recently completed, are a Graving Dock for ocean steamers, at the mouth of the Liffey, near Dublin, by Mr. G. Halpin, (M. Inst. C.E.,) and the Cork Waterworks by Sir John Benson.

Important lines of Submarine Telegraphs have recently been completed; and the anticipated greater certainty and speed in working them, indicate progress in this new branch of engineering science. Of these should first be mentioned the Red Sea Line, which extends from Suez to Aden, a distance of 1,200 nautical

miles, with two intermediate stations at Cosseir and Suakim. The cable was manufactured and submerged by Messrs. Newall and Co., under the superintendence of Mr. Lionel Gisborne, (Assoc. Inst. C.E.) The electrical arrangements have been carried out by Messrs. Siemens, Halske, and Co., of Berlin. This cable is not, at present, actually in operation; it is proposed, however, to extend it from Aden to Kurrachee. Other lines, between Constantinople and the Greek Islands, have been laid by Messrs. Newall and Co., and Mr. C. W. Siemens, (Assoc. Inst. C.E.); and but for a defect in a cable, lately submerged between Candia and Alexandria, India would, probably, have been telegraphically connected with the mother country, before the end of the present year. The British Government has ordered a cable for a line from Falmouth to Gibraltar, which will ultimately be extended to Malta and Alexandria, and form part of a great line to India. Mr. Lionel Gisborne has been appointed the Engineer, and Mr. C. W. Siemens, the Electrician to this undertaking. The Government has authorised a series of carefully-conducted experiments to be made, with a view to determine the best insulating medium, and the most effective outer covering for deep-sea lines.

A great step has been gained in the transit to the East, by the opening of the entire Egyptian Railway, between Alexandria and Suez, including the extensive wrought-iron bridge across the Nile, at Kaffre Azzayat. This bridge, which consists of thirteen spans of 128 feet each, was executed by Messrs. R. Stephenson and Co., and Mr. H. Grissell, (Assoc. Inst. C.E.,) under the immediate superintendence, in this country, of Mr. G. R. Stephenson, (M. Inst. C.E.); and was fixed by Mr. E. Price, (Assoc. Inst. C.E.,) the contractor for the bridge, under the direction of Mr. Henry James Rouse, the Chief Engineer to H. H. Said Pacha, Viceroy of Egypt.

In order to secure the safety of travellers, the Peninsular and Oriental Steam Navigation Company had urged upon H. H. Said Pacha, the Viceroy, through Mr. Davidson, their Superintendent in the Mediterranean, the necessity for the construction of a double line of rails between Alexandria and Cairo; for a regular system of trains; for an increased staff of English telegraphists; and for the employment of European engine drivers, station masters, &c. The three last suggestions were approved by the Viceroy, and the requisite orders have been issued for carrying them into effect. As regards the comfort of travellers, the Viceroy, among other improvements, has ordered:—first, the employment of a suitable number of competent officers, to superintend the arrangements for the landing and embarcation of the passengers at Alexandria and Suez, and for the protection of their

property; secondly, the establishment of proper vehicles for the conveyance of passengers between the railway station, or hotels, and the wharf at Alexandria, and between the railway terminus at Cairo and the hotels; and thirdly, the construction of proper stations and waiting-rooms, with European male and female attendants, at Alexandria, Kaffre Azzayat, Cairo, the Centre Desert Station, and at Suez.

From a return made to an order of the House of Commons, it appears, that the public works on which interest has been guaranteed by the Indian Government, and the amount guaranteed in each case, are:—

		£.
East Indian	Railway	12,731,000
Eastern Bengal	"	1,000,000
Calcutta and South Eastern	"	250,000
Madras	"	6,000,000
Great Southern of India	"	2,000,000
Great Indian Peninsula	"	10,000,000
Scinde	"	1,000,000
Punjaub Railway (including a line from Delhi to Lahore)		4,000,000
Bombay, Baroda, and Central India Railway		2,500,000
Indus Steam Flotilla		250,000
Madras Irrigation and Canal Company		1,000,000
		£40,731,000

The rate of interest guaranteed in nearly all these cases, is 5 per cent.

Some of these works have been alluded to in previous Reports, but the following statement of the progress made, may be interesting.

The works on the East Indian Railway have latterly proceeded with a rapidity before unknown. In Bengal, 45 miles have been opened, between Burdwan and the River More. This section crosses the River Adjai, with a bridge consisting of thirty-two arches, and the River More with a bridge of twenty-four arches, all of 50 feet span, and executed in brickwork; besides numerous smaller, but still considerable, streams. By the middle of next year, the Ganges will have been reached at Rajmahal. The bridges over the Keeul, consisting of nine spans of 150 feet, over the Soane, of twenty-eight spans of 150 feet, over the Tonse, of seven spans of 150 feet, and over the Jumna, of fifteen spans of 210 feet, are making satisfactory progress. The foundations consist, in all cases, of brick wells, sunk from 20 feet to 50 feet

through sand and gravel, and the superstructures are to be of iron girders, sent out from this country. The line between Allahabad and Cawnpore, 126 miles in length, is in full operation. The great stations at Allahabad and Cawnpore are rapidly advancing towards completion. The line beyond, as far as Agra, only waits the arrival of the permanent way. The rest of the line as far as Delhi, the route of which has been altered since the mutiny, is in full progress. The surveys of the line from Allahabad towards Bombay, called the Jubbulpore branch, were checked in the early part of the year, by the unsettled state of the country, and the murder of the two Chief Engineers, Messrs. Evans and Limnel. The surveys have again been commenced, it is to be hoped, under happier auspices. The receipts amount, on the line at present opened in Bengal, to £35 per mile per week; with an average passenger fare of less than seven-sixteenths of a penny per mile, and a rate for goods of less than one penny per ton per mile.

Of the Great Indian Peninsula Railway, 195 miles have been opened for traffic. This includes, on the South Eastern Line:—

From Bombay, viâ Callian, to Campoolee at the foot of the Bhore Ghât	71 miles
From Khandalla, at the top of the Bhore Ghât, to Decksal	106 „

and on the North Eastern Line:—

From Callian to Wassind	16½ „
The Mahim Branch	1½ „
Total . . .	195 miles.

It is stated, that the traffic returns have been most satisfactory; and as an evidence of the large use made of the line by the natives, it may be mentioned, that in the twelve months ending June, 1859, there were nearly twelve hundred thousand third-class passengers. Probably by this time, the South Eastern Line has been opened 50 miles beyond Decksal; and by Midsummer next, it is hoped, that the North Eastern Line will be ready for traffic from Wassind to the foot of the Thull Ghât, a distance of 25 miles, and from the summit of the Thull Ghât to Nassick, a similar distance of 25 miles. The works are now in progress on this contract as far as Bhosawul, being a length of 190 miles, under Messrs. Wythes and Jackson,—from Bhosawul to Jubbulpore, a distance of 332 miles, under Messrs. Duckett and Stead,—and upon the Nagpore Branch, a length of 263 miles, under Messrs. Lee, Watson and Aiton. The entire system is upwards of 1,100 miles in length.

The works upon the Bhore and the Thull Ghâts are of a very remarkable character, and cannot be done justice to by a cursory notice; it is to be hoped, therefore, that they may form the subject of future communications for the evening meetings. They comprise lofty viaducts, and numerous tunnels through hard trap rock. The viaducts were, at first, wholly composed of masonry, but latterly, iron girders have been substituted for the stone arches, as it was found impossible to obtain the services of the requisite number of masons, to complete the works as originally designed, within a reasonable time. The late Mr. Robert Stephenson was the Engineer-in-chief up to the period of his decease, since which Mr. G. Berkley, (M. Inst. C.E.,) has been appointed. Mr. J. J. Berkley, (M. Inst. C.E.,) is the Chief Resident Engineer in India.

On the Madras Railway, the principal works recently completed are the bridges over the Rivers Cauvery and Thoota. The former has twenty-two, and the latter twelve openings, each of 65 feet. These are spanned by wrought-iron plate girders, resting on masonry piers. The bridge over the River Palaar is composed partly of arches of masonry and partly of wrought-iron plate girders, on masonry piers, the spans in this case being also 65 feet. The line has already been opened to Goriattam, a distance of 96 miles from Madras, the eastern terminus; and the traffic on that section has shown the native appreciation of this mode of travelling. It is expected, that the line will be opened, by the end of the year, as far as Salem, a distance of 206 miles from Madras, and about half way to Beypore, the western terminus. The whole of the main, or South Western Line, 405 miles in length, will, probably, be opened towards the end of 1861, when there will be a through communication, by railway, across the peninsula, between the Coromandel and the Malabar coasts. The works on the North Western Line, which joins the South Western Line, 42 miles from Madras, have just been commenced. The whole of the Madras Railway is being constructed entirely by the Company's Engineers, without the intervention of contractors; and the system has hitherto been found to answer satisfactorily. The Engineer-in-chief is Mr. Hawkshaw, and the Chief Resident Engineer in India is Mr. J. M. Heppel, (M. Inst. C.E.)

In Scinde and the North-West Provinces of India, the lines of communication, consisting of the railway between Kurrachee and Kotree, 110 miles in length, the steam service upon the River Indus, and the Punjaub system of railways connecting Mooltan with Lahore, Umritsir and Delhi, are making rapid progress, under the direction of Mr. T. A. Yarrow, (M. Inst. C.E.). The railways are being constructed departmentally, that in Scinde by Mr. John Brunton, (M. Inst. C.E.), and that in the Punjaub by Mr. William Brunton, (M. Inst. C.E.), as Resident Engineers.

The navigation of the River Indus, between the upper terminus of the Scinde Railway, and the lower terminus of the Punjaub Railway is effected by steamers of exceedingly light draft, constructed from designs of Mr. Yarrow, by Mr. J. Scott Russell, (M. Inst. C.E.,) and by Messrs. Richardson, Duck and Co. The vessels for the tug service are being built of corrugated galvanised iron by Mr. John Hamilton, (Assoc. Inst. C.E.) The construction of the entire flotilla in India is intrusted to Mr. Alfred Warren, as Naval Architect and Marine Engineer.

The Eastern Bengal Railway has been commenced, and measures have been taken for vigorously prosecuting the works. The line starts from Calcutta, on the east side of the Hooghly, and its course runs up the left bank of that river, the East Indian Railway being on the right bank. It extends to Kooshtee, on the River Ganges, being a distance of 108 miles from the starting point, and it will pass through a district containing a population of about six hundred inhabitants per square mile. These works were originally under the direction of the late Mr. Brunel, but they have now been transferred to Mr. Hawkshaw.

Among the new lines which have been begun in India during the past year, is the Great Southern of India, under the direction of Mr. G. B. Bruce, (M. Inst. C.E.) It will intersect the delta of Tanjore, and is intended, ultimately, to connect this rich district with the interior, by means of a junction with the Madras Railway, and also to open up the extensive cotton districts of Madura and Tinnivelly in the south of India. The ultimate length of the line, as proposed, will be 300 miles. Of this 80 miles have been sanctioned by Government, and are now in process of construction, from Negapatam to Trichinopoly. The country has been found peculiarly favourable for the construction of a railway, and it is one of the most populous and flourishing districts in the south of India.

A commencement has also been made of the Calcutta and South Eastern Railway, under Mr. J. A. Longridge, (M. Inst. C.E.,) a line which, although of small extent, will greatly benefit the commercial interests, by opening to the trade of Bengal, a new port of great capability. The difficult and dangerous navigation of the Hooghly, and its gradual deterioration, coupled with the increasing size of the ships trading to India, naturally directed attention to the Mutla, an inland creek of easy access and navigation, with a minimum depth of water of 6 fathoms at low water of spring tides, up to within 30 miles of Calcutta.

During the present year the first steps have been taken in an enterprise which, though upon an experimental footing at present, promises, if its results are as favourable as there is good reason to anticipate, to rival even the railways in magnitude and

importance. Allusion is made to the formation of the Madras Irrigation and Canal Company, (the Act of Incorporation of which was obtained in May, 1858), for the construction of canals of irrigation and of transit, throughout the Madras Presidency and the adjoining states; and ultimately, in other parts of India. There is ample evidence to show, that the employment of capital in the provision and distribution of water, for the thirsty plains of India, is highly profitable; and that an abundant field still remains untouched. It is a favourable sign of the vigour infused into the administration of this vast empire, on its assumption by Her Majesty's Government, that measures have already been taken, on a comprehensive scale, to test the possibility of realising these advantages. The first operations of the company have reference to a plan for turning the waters of the Upper Kistnah and Zoombuddra through the valley of the Koondaur, into the bed of the Pennar, a smaller stream which falls into the sea near the town of Nellore. By this means, coupled with the formation of a canal, joining the Pennar with the Pulicat Lake, and the improvement of the existing line of navigation thence to the city of Madras, a communication is proposed to be made, by water, to the extent of 200 miles, between the capital and the inland districts, which, although fertile and populous, containing many millions of inhabitants, have, hitherto, been practically excluded from foreign markets, in consequence of the almost entire absence of serviceable roads. It is also hoped, that by a judicious outlay in improving the beds of the Upper Kistnah, and its affluents, the means of navigation may be still further extended, for some hundreds of miles into the interior. It is expected, that the cost of the works above referred to, will amount to from one, to two millions sterling, according to the extent to which the scheme is prosecuted. The experiment at present sanctioned, is limited to the expenditure of one million. There are many other projects of equal magnitude and promise, which only await investigation and approval. One of the chief of these, and perhaps the most likely to be first entered upon by the company, is a series of works for the irrigation of the delta of the Mahamiddy, in the neighbourhood of Cuttach, upon the same principles and with works of a similar character to those, which have been so successfully executed by the Madras Government, in the delta of the Godavery. The cost of the works required for improving the delta of the Mahamiddy would, probably, be from two to three millions sterling. The Engineer-in-chief of this undertaking is Colonel J. T. Smith, M.E., (Assoc. Inst. C.E.,) who, having formerly been in the Department of Public Works, became familiar with the habits of the natives, and with the methods of irrigation and of tillage to which they are accustomed.

Many suggestions have been made for the construction of a

pier, or landing jetty, at Madras, and for some years past, Colonel Sykes, M.P., has strenuously urged the erection of a pier, composed of iron columns founded on Mitchell's screw piles. This work has now been commenced by Mr. F. Johnson, and is being vigorously prosecuted. The length of the pier will be 1,000 feet, and the width 40½ feet, with a T-head 160 feet in length. The platform will be 15 feet above high-water mark.

The Indian Government, under the advice, chiefly, of Sir Proby Cautley, established, during the past year, competitive examinations for the admission of young Engineers into the Public Works Department in India. The applications were numerous; but it was found, that although many of the candidates possessed a competent knowledge of the fundamental principles of the science of Civil Engineering, and had acquired an acquaintance with its details and practice, yet they were deficient in a "knowledge of the mathematical laws by which the theory of Engineering is governed." Thus, only one candidate in sixteen could be recommended for admission to the public service. The examiners, therefore, advised, that the scale by which the merits of the candidates had been tested should be modified, or extended; and this recommendation has been followed, with very beneficial results to the public service.

The distant and flourishing, though comparatively little known, island of Mauritius is also seeking to obtain the advantages of a system of railways. A survey of the island, conducted for this purpose, at the instance of the Colonial Government, by Mr. J. A. Longridge, during the winter of 1858-59, has shown the great local benefits which the railway system will confer on the colony. It is fully expected, that before the end of the next year, the works will be in active progress, and from the peculiar features of the country, they will furnish materials for future communications of considerable professional interest.

Turning to the Continent of Europe, allusion must be made to the railway system in Spain, which is rapidly extending. It originated, exclusively, with English Engineers, principally Members, or Associates of this Institution, who have, unfortunately, too often reaped little, or no reward for their skill and labour; the practical execution of many of the principal lines having fallen into the hands of French Engineers, from the circumstance of the capital having been chiefly raised by the Bank of the Crédit Mobilier of France, or by the corresponding establishment in Spain, which is, in some degree, dependent on it. But the locomotive engines and other rolling stock have been, to some extent, supplied by English manufacturers. Several short lines in the vicinity of the great cities of Seville and Barcelona have been for some time in

operation; and in the course of the present year, the great line from Madrid to Alicante, with a branch to Valencia, was opened throughout. Other branches of this trunk line are in progress to Toledo and to Ciudad Rodrigo. Two main lines are in progress from Madrid towards France. First, the Northern of Spain, which proceeds by the Escurial, Valladolid, Burgos, Miranda and Vittoria, to the southern slope of the Pyrenees, at Alsasua. Secondly, the North Eastern route, which is by Guadalajara, Zaragoza, Tudela, Tafalla and Pamplona to Alsasua, where it joins the Northern of Spain, and whence a common line is projected to traverse the Cantabrian Pyrenees to Villafranca, and onward by Tolosa, St. Sebastian, and Passages, to Yrun, on the frontier of France, only 20 miles from where the French lines at present terminate. Of the above two trunk lines, parts of the Northern of Spain Railway, in the easier districts, are advancing towards completion, but no portion has been actually opened for traffic; whilst on the difficult parts, little has been effected. On the other line, towards Zaragoza, the first section from Madrid to Guadalajara has been opened for traffic, and some progress has been made on the other portions, particularly between Tudela and Pamplona. A commencement has been made at the bridge over the River Ebro, which is to be founded on iron cylinder piers, with wrought-iron girders spanning the openings. This bridge will be three-quarters of a mile in length. Great exertions are making on the line between Barcelona and Zaragoza; and it is stated, that during the last spring, as many as seven thousand men were at work upon it. Of the line from Santander to the head of the Grand Canal of Castile, which was under the directions of our late Member, Mr. Alfred S. Jee, the northern section near Santander, and the southern section next the canal, at Alar del Rey, have been opened for some time. The central portion of this line, passing near Reinosa, is also now in course of construction.

The Biscayan Railway, from the Port of Bilbao, to Miranda, on the Ebro, and thence along the right branch of the river to near Tudela, is now in course of construction by Messrs. Brassey, Paxton, and Wythes, under Mr. Vignoles, (M. Inst. C.E.) The length of this railway is upwards of 150 miles. It will traverse the Cantabrian Pyrenees, by a gradient of 1 in 70 for about 12 miles. The works are heavy in many places, particularly on leaving Bilbao, and on the ascent from the north, up the mountains. From the summit the fall is very easy, along the narrow valley of the River Bayas down to the Ebro. The manner in which the capital for the Biscayan railway was raised, deserves notice, as affording a good illustration of what commercial necessity will effect, and a splendid example to the rest of their countrymen, given by the merchants of a small Spanish town of less

than forty thousand inhabitants. Bilbao had, till lately, almost a monopoly for the supply of Madrid, and the intermediate country, with colonial produce; the merchants being men of wealth, and connected with the colonies, particularly with Cuba. The partial opening of the railway from Madrid to Alicante, began to affect the trade of Bilbao. The principal inhabitants immediately pressed their case upon the Spanish Government, and obtained a subvention of £5,000 per mile, towards a railway from that port; and among themselves and their colonial correspondents, they raised the required capital, in a few weeks, to complete the line into the interior. It will join the Northern Railway at Miranda, on the Ebro, and the Zaragoza Line, near Tudela. Thirty per cent. on the shares has been already paid, without a single defaulter, and the Engineers and contractors are pushing on the works with such vigour, that at the end of 1860, the railway will reach the foot of the mountains; and it is believed, that by the end of 1861, the line will be carried over the Pyrenees and through the passes beyond, to the Ebro; and that a third year will complete the works to near Tudela.

Two other main lines have been surveyed for the Spanish Government; one, about 200 miles in length, from Ciudad Rodrigo to Merida and the frontiers of Portugal, near Badajos, where it will join the line from Lisbon to Badajos; the other from the Northern Railway of Spain, near Valladolid, and through the Province of Galicia to Lugo, whence it will branch north-west to Corunna, and south-west to Vigo. Various other lines have been surveyed, and some smaller ones are in progress; but relative to them, authentic information is wanting.

The Spanish Government is anxious to extend railways throughout the Peninsula; and subventions are offered, varying from £4,000 to £6,000, and even £7,000 sterling per English mile, to induce capitalists and others to embark in these undertakings. But the interference of the Government in all the details of construction, through the medium of officials at every stage, forms too great a drawback to tempt English capital, except under peculiar circumstances. The iron and rolling stock for all the Spanish railways will, no doubt, be supplied from England; as it has been found, that they can be furnished from thence, better and cheaper than from the workshops of France, Belgium, or Germany.

In Italy, in Piedmont, and in Austria, political events have temporarily arrested the formation of new lines of railway; although the want of connecting lines, such as that between Genoa and Nice, by the shore of the Mediterranean, is universally admitted.

In Prussia and in Germany few great works are in progress, and only some comparatively unimportant branch lines of railways have been executed.

Holland has, at length, awakened from its apparent lethargy, and the States have authorised the formation of upwards of 600 miles of railway, which will involve the construction of three bridges of unusual extent, besides a vast number of smaller works of very difficult character. A grand ship-canal from Amsterdam direct to the sea is also projected, as well as the construction of a pier at Skeveningen, where passengers and mails from England can disembark from the steamers, at a distance of only four miles from the Hague.

In Sweden and in Norway the railways are slowly, but steadily, extending. In Denmark, the Government has employed Mr. Alfred Giles to effect the reclamation of a tract of land from the harbour of Copenhagen, and to construct 900 lineal feet of deep wharfage, and a dry dock 250 feet long, 61 feet wide, and 21 feet deep. These works, which are connected with the dockyard by a swing bridge over a canal 90 feet wide, necessitated the construction of a coffer dam 1,250 feet in length.

At Copenhagen, water and gas works have been recently constructed, under the superintendence of Mr. Simpson, (Past-President Inst. C.E.) The project of Mr. Murray, (M. Inst. C.E.,) to extend the harbour southward of the fortifications, has recently received the sanction of the Danish legislature. It is proposed to cut a channel 5 miles in length, through Kallebod Strand, between the islands of Amager and Zealand, into the deep water of the Baltic; and to reclaim land with the materials dredged in the new harbour. If carried into effect, this project will add much to the prosperity of the city.

The English system of waterworks appears to be making considerable progress abroad. During the past year, important works for the supply of Altona, from the Elbe, at a distance of eight miles, and under somewhat special circumstances, have been completed by Mr. Hawksley, and other works have been commenced by the same gentleman, in association with local Engineers, for the supply of the city of Stockholm, in Sweden, and of Bridgetown, in Barbadoes. As these works involve peculiarities of construction, consequent on the adaptation of waterworks to the requirements of climates in which the extremes of heat and cold prevail, a description of them will hereafter be presented to the Institution.

In Russia, the Riga and Dunaberg Railway, under the direction of Mr. Hawkshaw, is progressing, and will be completed, it is expected, in the course of the year 1861. Of the extensive system of railways being constructed under the direction of M. Zeiller,

for the Crédit Mobilier of France, the portion between Königsberg and Dunaberg has been already traversed by the Emperor, and will soon be open to the public.

The policy of the Imperial Government of Brazil has long been directed to every class of public improvement, and particularly to the internal communications, among which the railways stand first in importance. Four commercial cities on the seaboard have been selected as the starting points of railways, to proceed into the interior, viz., Recife, or Pernambuco, Bahia, Rio de Janeiro, and Santos. Upon the capital to be invested in these undertakings, the Brazilian Government offers a guarantee of 5 per cent., and also indorses a further guarantee of 2 per cent., by each province which these lines are to pervade, making an assured interest of 7 per cent.

The first section of the Don Pedro Segundo Railway at Rio de Janeiro was executed by Mr. E. Price, under a contract with the Brazilian Government; the length of the line is about 30 miles. Arrangements are making for extending it into the interior of the country, as soon as the important question of the mode of surmounting the great ascent from the coast, is settled.

The Pernambuco Railway was designed by Messrs. De Mornay, and the line was originally laid out by the late Mr. Borthwick. The works had made a slight progress prior to his death, which was shortly followed by that of Mr. Rendel, his successor. The direction of the works, which are being vigorously prosecuted, is now undertaken by Mr. Gregory, (M. Inst. C.E.,) and Mr. Peniston, (M. Inst. C.E.,) and the length under execution is about 80 miles. The first section, from Recife to Villa da Cabo, a length of about 19 miles, was opened on the 9th of February, 1858, and the traffic is so far developed as to produce, even now, a very fair return. The second section, of 17½ miles, which will open up an increased traffic in sugar, &c., is in a forward state, and will, probably, be completed by the spring, or summer of next year. The works on this section are heavy, and they have been impeded by a wet season of unusual severity.

The Bahia Railway is under the direction of Mr. C. Vignoles, by whose Son, Mr. Hutton Vignoles, (M. Inst. C.E.,) the line was originally laid out, and to him is intrusted the management of the works, the contract for which was taken by Mr. J. Watson, (M. Inst. C.E.) The length of this railway is nearly 80 miles, of which the first 30 miles are of a difficult character, including a viaduct about 1,000 yards in length, over an arm of the sea. It is erected on Mitchell's screw piles, with wrought-iron beams spanning the openings. The whole of the details of this viaduct were worked out by Mr. Francis Sheilds, (M. Inst. C.E.) This viaduct

will, probably, be completed early in January next; the first section of the railway will be opened by Midsummer, 1860; and the entire line will be completed in the course of the year 1863.

Both the Pernambuco and the Bahia Railways are designed to terminate, ultimately, on the River San Francisco, at, or near the point where further navigation towards the ocean ceases, which is nearly 300 miles above the mouth of the river. About midway in this distance occur the Grand Falls of Paulo Affonso, said to be only second to those of Niagara. An exploring expedition, sent by Mr. Vignoles, and conducted by Mr. Vivian, assisted by Mr. Walter Croubace, has determined, that a practicable, and not expensive route, may be found in continuation of the present Bahia Line: the total distance from the port of Bahia, to Ivaziero, on the left bank of the River San Francisco, being 400 miles. The concession of the extension is in the hands of the Bahia Railway Company. From the above projected terminus, the river, with its tributaries, is navigable for vessels not exceeding 6 feet draught, for upwards of 1,000 miles. It passes through land of the richest character, promising well for the future prosperity of the Brazilian Empire, when this region shall be opened.

The railway from Santos is better known as the San Paulo Line, the province through which it is to pass. The surveys and explorations were made two years ago, under the direction of Mr. Brunlees, by Mr. Fox. The peculiar character of the country appears to have led to the proposal for adopting inclined planes of about 1 in 10, for upwards of 5 miles. The whole country is very rugged and difficult, and will, it is believed, require other planes of 1 in 75 and 1 in 50 for short distances.

Several hundred miles of macadamised roads have been laid out by Mr. Hutton Vignoles, through the Province of Bahia, partly in connection with the railway, and under the energetic management of Mr. Watson, the contractor, they are fast approaching to completion. The works of the Mangaratiba Serra Road have also been carried out by Mr. E. B. Webb, (M. Inst. C.E.) The hydraulic works in front of the city of Rio de Janeiro, are now assuming considerable dimensions, under the care of Mr. C. Neate, (M. Inst. C.E.); and Mr. Law has undertaken the construction of the docks for that city. Gas works have also been established at Rio de Janeiro and at Pernambuco, which are said to be paying 15 per cent.; and similar works are in contemplation for Bahia.

In Brazil, the talents and energies of English Engineers are duly appreciated. Mr. C. B. Lane, (M. Inst. C.E.,) is the Chief Engineer to the Home Government at Rio; and Mr. W. Martineau, (M. Inst. C.E.,) at Pernambuco. In addition, most of the

Assistant Engineers, foremen and gangers, are Englishmen, and almost the whole of the iron, rolling and other stock, for these undertakings, has been sent from this country. The works have also, for the most part, been executed with English capital.

It is to be regretted, that Mr. Robert Stephenson did not survive to see the successful final completion and opening of the great Victoria Tubular Bridge, across the St. Lawrence, at Montreal. This structure is nearly 1¾ mile in length, the greatest span being 330 feet. It is unexampled in extent, and in the massiveness and peculiar construction of the masonry piers for resisting the pressure of the ice.

The principal Papers read during the past session were:—"Description of the Line and Works of the Railway from Lisbon to Santarem," by J. S. Valentine, (M. Inst. C.E.); "On the Railway System in Ireland, the Government Aid afforded, and the Nature and Results of County Guarantees," by G. W. Hemans, (M. Inst. C.E.); "On the use of Locomotive Power, on Gradients of 1 in 17, and Curves of 300 feet radius, on Railways in America," by T. S. Isaac; "Description of a Breakwater at the Port of Blyth; and of Improvements in Breakwaters, applicable to Harbours of Refuge," by M. Scott, (M. Inst. C.E.); "On the Performances of the Screw Steam-Ship 'Sahel,' fitted with Du Trembley's Combined-Vapour Engine; and of the sister ship 'Oasis,' fitted with Steam Engines worked expansively, and provided with partial Surface Condensation," by J. W. Jameson, (Assoc. Inst. C.E.); "On the Coefficients, T_e and T_r, of Elasticity and of Rupture in Wrought Iron; in relation to the volume of the Metallic Mass, its Metallurgic Treatment, and the Axial Direction of its constituent crystals," by R. Mallet, (M. Inst. C.E.); "Account of Experiments upon Elliptical Cast-Iron Arches," by T. F. Chappé, (M. Inst. C.E.); "On the Water Supply to the City of Melbourne, South Australia; comprising a brief description of the Melbourne Gravitation Waterworks," by M. B. Jackson, (M. Inst. C.E.); "On a New System of Axle Boxes, not requiring Lubrication, and without Liability to Heating," by P. A. de Brussaut; "On the Permanent Way of the Madras Railway," by B. M'Master, (Assoc. Inst. C.E.); "Description of the Entrance, Entrance Lock, and Jetty Walls of the Victoria (London) Docks; with a detailed account of the Wrought-Iron Gates and Caisson, and remarks upon the form adopted in their construction," by W. J. Kingsbury, (Assoc. Inst. C.E.); "On the Tyne Docks at South Shields; and the mode adopted for Shipping Coals," by T. E. Harrison, (M. Inst. C.E.); and "On the Manufacture of Malleable Iron and Steel," by H. Bessemer.

The following Telford and Watt Medals, and Council and Manby Premiums of Books, have been awarded to the Authors of some of these communications:—

1. A Telford Medal, to Michael Scott, M. Inst. C.E., for his Paper, "Description of a Breakwater at the Port of Blyth; and of Improvements in Breakwaters, applicable to Harbours of Refuge."
2. A Telford Medal, to Robert Mallet, M. Inst. C.E., for his Paper, "On the Coefficients, T_e and T_r, of Elasticity and of Rupture in Wrought Iron, in relation to the volume of the Metallic Mass, its Metallurgic Treatment, and the Axial Direction of its constituent crystals."
3. A Telford Medal, to Henry Bessemer, for his Paper, "On the Manufacture of Malleable Iron and Steel."
4. A Telford Medal, and the Manby Premium, in Books, to William Joseph Kingsbury, Assoc. Inst. C.E., for his Paper, "Description of the Entrance, Entrance Lock, and Jetty Walls of the Victoria (London) Docks; with a detailed account of the Wrought-Iron Gates and Caisson, and remarks upon the form adopted in their construction."
5. A Watt Medal, to James Wardrop Jameson, Assoc. Inst. C.E., for his Paper, "On the Performances of the Screw Steam-Ship 'Sahel,' fitted with Du Trembley's Combined-Vapour Engine; and of the sister ship 'Oasis,' fitted with Steam Engines worked expansively, and provided with partial Surface Condensation."
6. A Council Premium of Books to Thomas Sebastian Isaac for his Paper, "On the use of Locomotive Power, on Gradients of 1 in 17, and Curves of 300 feet radius, on Railways in America."
7. A Council Premium of Books, to Matthew Bullock Jackson, M. Inst. C.E., for his Paper, "On the Water Supply to the City of Melbourne, South Australia; comprising a brief description of the Melbourne Gravitation Waterworks."

It should be mentioned that, in accordance with an established rule, two of the Papers, being by Members of the Council, Mr. Harrison and Mr. Hemans, were not considered in the adjudication of Premiums.

Although the Papers have been comparatively few in number, they are in excellence and in the variety of the subjects treated, quite equal to those of former years, as was evident from the interesting and animated discussions to which they gave rise. Indeed, about one-half of the whole number of Meetings was entirely occupied by

discussions, which are often the means of eliciting valuable and extended information that would not, otherwise, be obtained.

The Papers by Mr. Valentine, Mr. Hemans, Mr. Isaac, and Mr. M'Master referred to Railways in Portugal, Ireland, the United States, and India, respectively. That by Mr. Valentine, a "Description of the Line and Works of the Railway from Lisbon to Santarem," gave an account of the first railway executed in Portugal. After alluding to the entire absence of facilities for internal communication in that country, prior to the year 1853, the method of granting concessions, which was founded on the French system, was detailed. It was agreed, that this system was objectionable, as it fettered the freedom of action of the Engineer, on whom the responsibility, in reality, rested. The concessions subsequently granted were then alluded to, and a narrative was given of the mode of obtaining land for railway purposes. The line and works were next minutely described, and it was shown, as a result, that the partial opening of the line, for passenger traffic alone, had proved, that the peasantry preferred that mode of travelling to the old and slow methods to which they had been accustomed, even though it was more expensive.

The Paper by Mr. Hemans, "On the Railway System in Ireland, the Government Aid afforded, and the Nature and Results of County Guarantees," was suggested by the Address of Mr. Locke, M.P., President, which related chiefly to French railways. It appeared, that in 1836, Ireland was a blank, as far as regarded railways. In that year, a Government Commission was appointed "to inquire into the manner in which railway communications could be most advantageously promoted in Ireland." The main recommendations of their Report, which was finally made in July, 1838, were considered sound and good. These were examined in detail, and were contrasted with the results which had actually taken place. No steps, however, were taken by the Government, so that speculation languished, until the time of the railway movement in England, when the country began to make for itself, and with little regard to anything like a national system, the various lines now in existence, almost all of which were originated in 1845 and 1846. One of the recommendations of the Commission was, that Government should advance the capital required for the construction of the chief lines, and that the principal and interest of such advances should be secured on local, or baronial rates, in such districts as should consent so to obtain the benefit of railways. This had been successful in the only case attempted, the line from Athlone to Galway; but, for some unaccountable reason, the most determined official opposition was given to the guarantee clauses in the House of Lords, and hence, many districts were even now deprived of the benefits of railways.

In Mr. Isaac's Paper, "On the Use of Locomotive Power, on Gradients of 1 in 17, and Curves of 300 feet radius, on Railways in America," allusion was first made to the Baltimore and Ohio Railway, extending from the city of Baltimore, on the Chesapeake Bay, to Wheeling, on the Ohio River. It was stated, that this was the first railway in operation in the United States, the company having been organised in 1827, and a portion of the line opened in 1830. In the construction of this road, the various ranges of the Alleghany Mountains had to be encountered; and attention was particularly directed to the daring enterprise, which could project and undertake the construction of a railway, at that early period, through a region where the difficulties were of such a gigantic kind The more immediate object of the Paper, was to describe the Mountain Top Track, on the Virginia Central Railroad, where it crossed the Blue Ridge Mountains, at Rock Fish Gap. It was $4\frac{1}{3}$ miles in length, with a ruling gradient of 1 in 18·87; but on the lower half mile of the eastern slope, the gradient was 1 in 17·86, on curves of 570 feet radius and upwards, and the minimum gradient, on curves of 500 feet radius, was 1 in 22·22. The length of the eastern slope was 2·37 miles, with an average gradient of 1 in $20\frac{1}{2}$, and of the western slope 1·89 mile, with an average gradient of 1 in 22·22. This track had been successfully worked by locomotive power for upwards of four years, without a single accident. It was stated, that experience had proved, that a locomotive could draw a load double its own weight up a gradient of 1 in 17, at a speed of 8 miles per hour. In the course of the discussion, the circumstances under which steep gradients could, with propriety, be adopted, were considered; and it was remarked, that inclines of 1 in 10, or 1 in 17, or even 1 in 40, would only be resorted to from necessity, as, for instance, where it was desirable to prevent a break of gauge in a long line of railway, as they were attended with a heavy cost for working expenses.

Mr. M'Master, in his Paper, "On the Permanent Way of the Madras Railway," remarked, that two leading features in the construction of railways in India were, the cheapness of the works entirely dependent on native labour and the resources of the country, and the expense of those dependent upon England for the supply of materials. He stated that, as yet, almost every part of the permanent way had to be supplied from England; though he believed, ultimately, the forests and jungles of India would be found capable of supplying many hard and durable woods suitable for sleepers, as well as for other purposes

Mr. Scott, in his "Description of a Breakwater at the Port of Blyth, and of Improvements in Breakwaters, applicable to Harbours of Refuge," referred also to the theory of waves, and to the

theory of hydraulic construction, including the form and methods of building. After describing the port of Blyth, and the means adopted for improving the harbour by the erection of a breakwater, consisting of a timber casing filled with stone, the Author proceeded to remark, that the systems pursued at Dover, Alderney, Portland, and Holyhead did not appear to secure rapid execution. He, therefore, suggested, that the plan of construction successfully adopted at Blyth, might be employed in other cases. He argued that, even if the new arrangements were regarded merely as a means for forming the backbone, as it were, of a more permanent structure, it was the best and cheapest method of attaining the object desired; and that, under the new system, a harbour would be inclosed in five years, instead of occupying twenty years, as on the old system. This Paper led to a prolonged discussion, in the course of which the works at Portland, Holyhead, Dover, Alderney, &c., were alluded to, the relative merits of flat slopes, or vertical faces were entered upon, and the advantages of the proposed system were strongly contested. Mr. John Murray, in his remarks on the form and cost of breakwaters, spoke of the plan adopted by the French Engineers at Marseilles, of not mixing any small material with the large blocks, and suggested the extension of the system, by the use of material of different sizes at various depths. He also advocated the use of béton blocks of 20 tons weight, for the upper portions. The system upon which the Harbours of Refuge were being executed, was thought to be objectionable, and it was urged, that no person should be placed upon a commission of inquiry on this subject, who was pledged to any particular views; nor should the execution of any work be intrusted to any member of a commission, by whom that work had been recommended.

The Paper by Mr. Kingsbury, "Description of the Entrance, Entrance Lock, and Jetty Walls of the Victoria (London) Docks, &c.," gave a minute account of the different works involved in this undertaking, which, from their magnitude, and the peculiarity of their construction, presented considerable interest. It will be remembered, that the sides of the entrance of the channel leading to the tidal basin, and of the lock, were described as being composed of concrete walls, faced with cast-iron piles and plates. The side walls of the jetties were described as a combination of cast-iron piles, vertical brick inverts and concrete, with clay puddle. A detailed account was also given of the wrought-iron gates and caisson, and some remarks were made upon the form adopted in their construction. A caisson of peculiar form and construction was stated to have been used in place of a cofferdam, in completing the entrance works. The new caisson was built of a rectangular form in side elevation, the heel posts being vertical, and shaped like those of the gates. In plan, it was similar to one leaf

of the gates, and it extended across the span of 80 feet between the lock walls. It was divided into four horizontal and two vertical compartments, so arranged, that by regulating the admission of water into them, it could be floated with the convex side downwards, nearly in a horizontal position, and be raised into an upright position when required. The casualties which occurred during the construction of the docks were fully described; and the latter portion of the Paper treated of the advantages of the cylindrical form adopted for the gates, with respect to economy of material and general arrangement.

The Paper, "On the Tyne Docks at South Shields, and the mode adopted for Shipping Coals," by Mr. T. E. Harrison, described the utilisation of a large area in the Tyne, called Jarrow Slake, previously covered with water at spring tides. The extent of the works and the mode of execution were then detailed, from which it appeared, that the first operation was to form a large culvert round the head of the dock area, to receive and carry off the upland waters. The sustaining power of the mud, or slake, was found, by experiment, to amount to 7 cwt. per superficial foot. The primary object of these docks was, to provide accommodation for the shipment of coals brought to South Shields by the North Eastern Railway Company. The extent of this trade was alluded to. A brief account was then given of the different methods of shipping coals used at the northern coal ports during the last forty-seven years, and the reasons which induced the adoption in the Tyne Docks, of the system of shipping by spouts. The arrangements for delivering the coal at different levels, so as to suit the varying level of the ship's deck, for economising space at the jetties, by letting the vessels overlap each other when at the shipping places, and for saving manual labour, by laying out the ground above, so that gravity was called into operation to the utmost possible extent, were all minutely described. Great expedition had been thus attained, and it was mentioned, that on the day of the opening, a screw steamer entered the docks, received on board 420 tons of coal in fifty-five minutes, and immediately went to sea.

Mr. Jameson, in his "Account of the Performances of the Screw Steam Ship 'Sahel,' fitted with Du Trembley's Combined-Vapour Engine; and of the sister ship 'Oasis,' fitted with Steam Engines worked expansively, and provided with partial Surface Condensation," gave, in the first place, a brief description of the combined-vapour engine. From this it appeared, that the principle of the engine was based upon the fact, that the condensation of a liquid, such as water, boiling at a high temperature, might be effected by surrounding an external condenser with a liquid, such as ether, boiling at a low temperature. Thus, in a steam boat

with a combined engine, one cylinder would be worked with steam in the ordinary manner, and the other cylinder, with the vapour of ether. After alluding to the experience gained in the 'Du Trembley,' the 'France,' and the 'Brésil,' and to the application of the system in the 'Sahel,' 'Zouave,' and 'Kabyle,' an examination was made of the tabular records of the performances of the two ships, 'Sahel' and 'Oasis.' From this the following results, in favour of the combined-vapour engine, were deduced; first, a weight and place available for 50 additional tons of cargo, or an increase of one-sixth; secondly, a diminution in the consumption of fuel of 40 per cent.; and thirdly, an increase of one-ninth in the speed of the ship. There were attendant disadvantages, but still the actual saving was believed to be such as to merit attention. Only three accidents had occurred during five years, and these were stated to have taken place, when the engines were not at work, when the fires were extinguished, and the ships were in port. No extra insurance had ever been paid on the ships, on account of their having ether on board. In the discussion, the opinion was expressed, that surface condensation would, ultimately, supersede condensation by injection. A comparison of the performances of the combined-vapour engine with those of ordinary-vapour marine engines, made by experienced builders, seemed to show, that the latter consumed, at least, one-half more fuel than the former; and that in fact, the combined engines were as economical, in the consumption of fuel, as some of the best engines employed for pumping. The disadvantages of working without a steam jacket to the cylinder, especially when using steam very expansively, were also pointed out. It was urged, that the true measure of the efficiency of an engine, was the quantity of water passing through it, as steam, in a given time, and that there was no practical value in the employment of ether; for if high-pressure steam was used, expanded in a double cylinder engine, with proper precautions against radiation, equally economical results would be obtained.

In the Paper, "On the Water Supply to the City of Melbourne, South Australia; comprising a brief description of the Melbourne Gravitation Waterworks," Mr. M. B. Jackson described, first the situation of the city, and then the different schemes which had been proposed during the fourteen preceding years, for supplying it with water, a necessity which was increasing in importance, as at the end of 1857, the population amounted to nearly one hundred thousand inhabitants. Finally, it was decided to adopt the River Plenty as the source, in accordance with the suggestion of Mr. Blackburn. The water was derived from the Mount Disappointment range of granitic hills, whence there flowed a number of streams, which, when united, after passing through the swamps,

formed the River Plenty. The works, which were carried out by the Author, consisted in cutting a watercourse, from the river to the Yan Yean reservoir, through a ridge of hills, which necessitated a tunnel a quarter of a mile in length, and in forming an embankment across a valley, between two spurs of hills, in order to retain the rain and flood waters in the reservoir. There was a well tower at the foot of the inner slope of the embankment, and another tower and valve chest on the outer slope, whence the main pipes proceeded to the city. At the commencement, this main was 30 inches in diameter, but it was, subsequently, reduced to 27 inches and, ultimately, to 24 inches. The distribution of the water commenced at 19 miles from Yan Yean, and, including this length of main, there were nearly 104 miles of pipes laid, varying from 24 inches to 3 inches in diameter. A series of Appendices contained Reports of the analysis of the waters, and statements of the rainfall and evaporation in various localities. In the discussion, it was stated, that the method of proceeding adopted in similar cases to that of Melbourne was, first, to ascertain the extent of the drainage area; secondly, to calculate the amount of rainfall, by taking an average of a number of years' observations in the neighbourhood; and, thirdly, to consider the quantity of rainfall that could be collected into any reservoir, which it was practicable to make in the district.

Mr. Mallet, in his experimental inquiry, "On the Coefficients, T_e and T_r of Elasticity and of Rupture in Wrought Iron, in relation to the volume of the Metallic Mass, its Metallurgic Treatment, and the Axial Direction of its constituent crystals," described the difficulty of obtaining very large forgings of a cylindrical form, quite sound, which he attributed to the play of molecular forces. He suggested, that such large forgings should be constructed and worked hollow. Attention was directed to the apparent superiority of puddled steel, for supporting the forces by which the ordinary forged masses of wrought iron were fractured, especially as by the employment of smaller and lighter masses, greater strength in shafts, &c. could be secured. It was thought, that this material would become an important adjunct in the construction of machinery, in the building of vessels of light draught of water, and for artillery of the largest calibre.

Mr. Bessemer, in his Paper, "On the Manufacture of Malleable Iron and Steel," gave an account of his process of converting crude pig-iron into malleable iron, while in a fluid state, by retaining the fluidity of the metal for a sufficient time, to admit of its being cast into moulds, without the employment of any fuel in the process. It was mentioned, that gold, silver, copper, zinc, tin and lead were refined, while in a fluid state, and were then cast into ingots, and there seemed to be no reason why iron should

remain an exception to the general rule. The form of the converting vessel which had been found most suitable for the purpose, was then described, some details of the processes being given at the same time. As large masses could be cast, of a homogeneous malleable metal, in any desired form, the operation of welding now employed, whenever large masses were required, would become unnecessary. The economy of production for large plates was adverted to, and the facility of forming masses of malleable iron and of steel suitable for ordnance, was also pointed out.

The Library continues to be enriched by the valuable charts published by the Admiralty, and many useful documents, printed by order of the Indian Government; these are transmitted by our Associate, Captain Washington, R.N., the Hydrographer, and Mr. Juland Danvers. Exchanges of proceedings with Foreign and Home Scientific Societies are regularly made, and the number is extending.

The binding of the periodical and other works is progressing, and the re-arrangement of the Library will be proceeded with, in the course of the ensuing year. The Council would again impress upon the Members, the importance of their presenting copies of any Reports made upon works on which they may have been engaged, in order that they may be available for future reference. The Council have pleasure in announcing, that Mr. George Robert Stephenson has expressed the intention of presenting the portrait, by Briggs, of the late Mr. George Stephenson,—that Messrs. Isambard and Henry Brunel have kindly offered a portrait, by Horsley, of their late lamented Father,—and that Mr. Joseph Cubitt has promised a portrait, by Boxall, of your Past-President, Sir William Cubitt. These valuable additions to the collection already on the walls of the Meeting-room, will be received with gratitude, and it is confidently hoped, that they will induce further contributions, so that the series of portraits of Past-Presidents may soon be rendered complete.

The amount of arrears of subscriptions of 1859, due November 30th, is—

	£. s. d.	£. s. d.
From Members of all classes, residing abroad .	51 19 6	
From Members of all classes, residing in the United Kingdom	149 2 0	
		201 1 6
The amount of arrears for 1857 and 1858, is—		
From Members of all classes, residing abroad .	32 11 0	
From Members of all classes, residing in the United Kingdom	70 17 6	
		103 8 6
Total		£304 10 0

It will be observed, that arrears of more than two years' standing, are excluded from this statement, the Council having determined to deal specially with all these cases, under the advice of a sub-committee.

The tabular statement of the transfers, elections, deceases, and resignations of Members of all classes, during the years 1857-58 and 1858-59, appears thus:—

—	Honorary Members.	Members.	Associates.	Graduates.	Annual Increase.
1857-58.					
Transferred to Members . .	..	..	9		
Elections	..	11	25	..	36 − 14 = 22
Deceases	1	6	3	..	14
Resignations	..	..	4	..	
1858-59.					
Transferred to Members . .	..	..	4		
Elections	1	16	41	..	58 − 21 = 37
Deceases	1	7	9	..	21
Resignations	..	1	3	..	
Members of all Classes on the Books, November 30, 1859 .	25	332	523	14	= 894

If the Honorary Members and Graduates are omitted from the calculation, the annual increase of Members and Associates stands thus:—

Years.	Members Elected.	Associates Elected.	Total Elected.	Deceases, Resignations, and Erasures.	Effective Increase.
1854	20	37	57	33	24
1855	7	24	31	13	18
1856	10	24	34	24	10
1857	12	57	69	23	46
1858	11	25	36	13	23
1859	16	41	57	20	37

The following Member and Associates, having tendered their resignations, have been permitted to retire from the Institution:—Mr. George Edwards, Member; Messrs. William Brown, John William Byrne, and Robert Murray, Associates.

The deceases during the past year have been:—Earl De Grey, Honorary Member; Messrs. Isambard Kingdom Brunel, Hugh Ebrington Fortescue, William Hartree, Daniel Mackain, Robert

Stephenson, M.P., Thomas Storey, and Alexander Wright, Members; James Barrett, Samuel Bennett, Robert Cantwell, George Gardner Donaldson, Robert Barlow Gardiner, Edward Highton, John Houldsworth, Edward Hughes, and George Mills, Associates.

The Memoirs of our late friends will be found in the Appendix to this Report.

Numerically the deceases scarcely exceed the average, but the loss to the Institution of two such Members as Isambard Kingdom Brunel and Robert Stephenson, cannot be adequately estimated. Both have been prematurely removed in the prime of life, and in all the vigour of their intellect. The former died on the eve of the completion of one of his gigantic and original conceptions, after successfully combating great difficulties in the execution of many peculiar constructions; and the other, when it might have been hoped, that the practical experience of many years in the prosecution of great and successful works, would have rendered him useful to his country, in the House of Commons, and to the Government as an adviser, for which he was eminently qualified, not only by his knowledge, but by the uprightness of his character.

Mr. Robert Stephenson, among other munificent legacies to public bodies, has bequeathed to this Institution the sum of Two Thousand Pounds, the announcement of which, the Council feel persuaded, will be received with kindly feelings analogous to those which prompted the gift. It will be for the succeeding Council to propose the mode of appropriating the interest of this fund, in such a manner as to connect the name of Stephenson, permanently with the Institution.

The financial position of the Institution continues to be very satisfactory. There is an available balance of £1,356. 3*s.* 1*d.* against £1,032. 10*s.* 11*d.*, shown in the Report of the previous year, or an excess in the year of upwards of £300. The Council, considering that the balance at the banker's should not be allowed to remain unproductive, were enabled, in May last, to place £1,000 on deposit at interest, with the Union Bank of London; this, with the balance in the hands of the Treasurer, amounting to £356. 3*s.* 1*d.*, makes up the total sum previously mentioned. On comparing the last two years' accounts, it will be seen, that the increase of revenue has arisen from the election of a greater number of Members, and that the larger expenditure has been caused by the second parts of Vols. VII. and VIII. of the 'Minutes of Proceedings,' which were in arrear, having been issued and paid for within the last twelve months. It should be stated, that the Council unanimously resolved, to raise the salary attaching to the office of Secretary from £300 per annum, at which it had remained for

twenty years, to £400 per annum, dating from the 1st of January, 1859. It had long been felt, that the stipend was insufficient for the duties of the office; and it was only because the finances did not, up to the present time, appear to justify an increase, that this step was not sooner resolved upon.

During the year, the series of Minutes of Proceedings up to and including the volume for 1857-8, has been completed, by the publication of Vol. VIII., Part 2, and of Vol. XVII. The Minutes of the past Session, forming Vol. XVIII. of the series, are printed, and will be issued early in 1860. Some delay has arisen from the difficulty in procuring materials for the Memoirs of the deceased Members, and in obtaining the drawings for the numerous plates illustrating the volume.

In the Balloting List for Members of Council, which has already been issued to the Members, it will be seen, that Mr. G. P. Bidder, the senior Vice-President, is proposed for election as President, Mr. Locke's term of office having expired. Two vacancies occur among the Vice-Presidents, in consequence of this nomination and of the decease of Mr. Brunel; Mr. Fowler and Mr. C. H. Gregory are proposed for these offices. The new names submitted for your consideration are Messrs. John Murray, James Abernethy, John Frederick Bateman, and George Robert Stephenson, as Members; and Messrs. William Bird, Captain Huish, Henry Arthur Hunt, and Frederick Marrable, as Associates.

The Council, in resigning their trust, beg to thank the Members for the support accorded to them on all occasions, and would ask for their successors the same kind co-operation they have experienced, without which the Institution cannot continue to make the progress which has, up to the present time, marked its career.

ABSTRACT *of* RECEIPTS *and* EXPENDITURE

RECEIPTS.

Dr.	£.	*s.*	*d.*	£.	*s.*	*d.*
To Balance in the hands of the Treasurer				1,032	10	11
— Subscriptions and Fees :—						
Arrears	160	13	0			
Current	2,061	3	0			
Fees	182	14	0			
Life	98	3	6			
				2,502	13	6
— Publication Fund				47	19	0
— Council Premium Fund				60	13	6
— Publications :—Sale of Minutes of Proceedings				116	8	3
— Manby Premium				20	15	10
— Telford Fund :—						
Dividends :—6 months, due Christmas, 1858, on £2,551. 15*s.* 10*d.*, 3 per Cent. Reduced Consols	37	9	7			
6 months, due Lady-day, 1859, on £2,342. 17*s.* 1*d.*, 3 per Cent. Reduced Consols	34	8	3			
6 months, due Midsummer, 1859, on £2,551. 15*s.* 10*d.*, 3 per Cent. Reduced Consols	37	9	7			
6 months, due Michaelmas, 1859, on £2,342. 17*s.* 1*d.*, 3 per Cent. Reduced Consols	33	4	10			
				142	12	3
				£3,923	8	3

from the 1ST DEC., 1858, *to the* 30TH NOV., 1859.

PAYMENTS.

Cr.	£.	s.	d.	£.	s.	d.
By House, Great George Street:						
Rent	366	8	2			
Rates and Taxes	46	6	9			
Insurance	18	19	9			
				431	14	8
— Salaries				375	0	0
— Donation to late Cashier and Collector				50	0	0
— Clerk, Messengers, and Housekeeper				164	16	0
— Postage and Parcels:—						
General	35	0	2			
Parcels	1	4	11			
				36	5	1
— Stationery, Engraving, Printing Circulars, Cards, &c.				62	19	10
— Coals, Candles, Oil, and Gas:—						
Coals	21	10	0			
Candles	0	17	6			
Oil	1	19	0			
Gas	17	19	3			
				42	5	9
— Tea and Coffee				28	14	11
— Library:—						
Books	5	17	6			
Periodicals	27	11	10			
				33	9	4
— Publication:—Minutes of Proceedings				1,239	9	0
— Council Premiums				27	15	5
— Watt Medal				4	2	0
— Manby Premium				11	5	10
— Diplomas for Members				7	1	6
— Manuscripts, Original Papers, and Drawings				1	5	0
— Winding and Repairing Clocks				1	10	0
— Incidental Expenses:—						
Gratuities and Christmas Gifts	1	16	0			
Occasional Assistance	3	4	10			
Assistance at Meetings	8	15	0			
Beating Carpets and Sweeping Chimneys	3	4	6			
Household Utensils, Repairs, and Expenses	32	10	6			
				49	10	10
				2,567	5	2
— Deposit in Union Bank of London	1,000	0	0			
— Balance in the hands of the Treasurer	356	3	1			
				1,356	3	1
				£3,923	8	3

Examined and compared the above Account with the vouchers in the Cash Book, and find them to be correct, leaving a Balance in the hands of the Treasurer of Three Hundred and Fifty-six Pounds, Three Shillings and One Penny.—November 30th, 1859.

(Signed) WILLIAM POLE, HENRY MAUDSLAY, } *Auditors.*
CHARLES MANBY, *Secretary*

December 5th, 1859.

APPENDIX

TO THE

ANNUAL REPORT.

MEMOIRS.

PHILIP, EARL DE GREY was the elder of the two sons of Thomas Robinson, second Lord Grantham, and of Lady Mary Jemima Yorke, daughter of the second Earl of Hardwicke. He was born at Whitehall, on the 8th of December, 1781. In 1786, he succeeded his Father in the Barony of Grantham, being at the time but five years of age, and in 1833, he became Earl De Grey. His education was completed at St. John's College, Cambridge, where he graduated in 1801. During Sir Robert Peel's short administration in 1834-35, he held the office of First Lord of the Admiralty, on which occasion he was made a Privy Councillor. When Sir Robert Peel again came into power in 1841, Earl De Grey was selected by that eminent statesman, for the high appointment of Lord Lieutenant of Ireland. He discharged the functions of his position impartially, and with much credit, up to June, 1844, when he retired, to the great regret of the people of Dublin; for, as the representative of the Sovereign, the hospitalities at the Vice-regal Court were sustained most liberally, not alone by the Noble Earl, but by his estimable Countess, who gave considerable encouragement to the manufactures of her native country. On his retirement from Ireland, the Noble Earl may be said to have relinquished political life, for beyond an occasional vote in support of the Liberal-Conservative party, he rarely interfered in political matters.

The late Earl having sedulously cultivated a good natural taste for architecture, became President of the Royal Institution of British Architects, in the year 1835. This office he held during the long period of twenty-four years, and he presided at the opening Meeting of the Session, only one week before his death. He took, from the first, the greatest interest in its welfare; it was he, who obtained for it a Charter of Incorporation, and it was mainly through his exertions, that Her Majesty was led to found the Royal Medal for Architecture, annually awarded by the Institution. At the Meetings for the Presentation of Prizes, he had ever words of

encouragement and hope for the younger recipients, warm and hearty congratulations for the elder. In the words of Professor Donaldson, "the Institute owed Earl De Grey a deep debt of gratitude, for much of the success which had attended its operation, and the high position which it held in the public estimation, and in that of all Europe, was to be attributed, in great part, to the warm and untiring interest which he had manifested in its behalf."

He was also President of the Architectural Museum, and took the chair on the occasion of its first public meeting; he was a Fellow of the Royal Society and of the Society of Antiquaries, and was connected with most of the other learned institutions. He was elected an Honorary Member of the Institution of Civil Engineers, on the 4th of June, 1839.

He died suddenly on the 14th of November, 1859, in the seventy-seventh year of his age, and, leaving no male issue, his titles devolved on his Nephew, the Earl of Ripon. The late Earl had been, for many years, Lord Lieutenant and Custos Rotulorum of Bedfordshire, an Aide-de-Camp to Her Majesty, and in 1844, he was nominated a Knight of the Order of the Garter; he was also Lieutenant-Colonel Commandant of the Yorkshire Hussar Regiment of Yeomanry Cavalry, a command he had held upwards of forty years.

MR. ISAMBARD KINGDOM BRUNEL was the only Son of the late Sir Marc Isambard Brunel, whose mechanical genius and originality of conception he largely inherited. Young Brunel was born at Portsmouth, in the year 1806, at the period when his Father was engaged on the block machinery for the Royal Dockyard. He received his general education at the Collège Henri Quatre, at Caen, where, at that time, the mathematical masters were particularly celebrated, and to his acquirements in that science may be attributed the early successes he achieved, as well as the confidence in his own resources which he displayed throughout his professional career. On his return to England, he was, for a time, practically engaged in mechanical engineering, at the works of the late Mr. Bryan Donkin, and at the age of about twenty, he joined his Father in the construction of the Thames Tunnel, where he attained considerable experience in brickwork and the use of cements, and more especially, in meeting and providing for the numerous casualties to which that work was exposed. The practical lessons there learned were invaluable to him; and to his personal gallantry and presence of mind, on more than one occasion, when the river made irruptions into the Tunnel, the salvation of the work was due. One of his first great independent designs was that selected for the proposed suspension-bridge

across the River Avon, from Durdham Down, Clifton, to the Leigh Woods, which he owed to the fact, that upon the reference of the competing designs to two distinguished mathematicians for the verification of the calculations, his alone was pronounced to be mathematically exact. Want of funds prevented, at that period, the carrying out of the design, which there are now some hopes of seeing executed, by transplanting to that site the present Hungerford Suspension-bridge, which is itself the work of Mr. Brunel.

His introduction to Bristol led to his appointment as Engineer to the docks of that city, which he materially improved. He had been previously engaged in the construction of the old north dock at Sunderland, and subsequently, he was consulted about the design for the Bute Docks at Cardiff.

In 1833-34, he was appointed Engineer to the Great Western Railway, and whilst engaged upon it, he matured his views of the broad gauge, relative to which he sustained one of the hardest-fought engineering contests on record. This work placed his reputation high among Engineers, and henceforth, his mental and physical powers were taxed almost beyond those of any other member of the profession. His attention to all the details of even the smallest works was unremitting; and the Hanwell and Chippenham Viaducts, the Maidenhead and other masonry Bridges, the Box Tunnel, and the iron structures of the Chepstow and Tamar Bridges on the extension of the railway to the west, attest the boldness and originality of his conceptions, his taste in designing, and his skill in the use of various constructive materials. The partial failure at the opening of the line appeared only to incite his inventive faculties, and to afford a field for the exhibition of his great powers. All the physical impediments were met and conquered, and his perseverance was ultimately crowned with success, in attaining a speed of travelling, combined with comfort and security, hitherto unrivalled. In the attempted adaptation of the atmospheric system of propulsion to the South Devon Railway, he was, however, signally unfortunate, in spite of all the ingenuity displayed; but this failure served to bring into view a most pleasing feature of his character, for while he duly paid up all the calls upon the stake he had in the undertaking, he, at the same time, refused to accept the professional emoluments to which he was entitled.

His services were in constant demand in railway contests before Committees of the Houses of Parliament, and he was employed to construct the Tuscan portion of the Sardinian Railways, as well as to advise upon the Victorian lines in Australia, and the Eastern Bengal Railway.

Intimately, however, as the name of Isambard Brunel will ever

be connected with the railway epoch in Great Britain, it is, probably, as the originator of the system of extension of the dimensions of steam vessels, that he will be best known to posterity. The 'Great Western' steam ship was his first innovation. In that vessel, which was much larger than any previously constructed, he had the able assistance of Mr. Paterson, of Bristol, as the shipwright and of Mr. Joshua Field, (Past-President Inst. C.E.,) as the constructor of the engines, and in spite of adverse anticipations, even among practical men, the most triumphant success crowned his efforts, and demonstrated the correctness of his views.

His attention was, at that time, directed to propulsion by the screw, a subject on which Mr. F. P. Smith, (Assoc. Inst. C.E.,) had been long and patiently labouring, and the experiments made by Mr. Brunel, in his voyages on board the 'Archimedes,' convinced him of the practicability of the adaptation of the system to large steam vessels. He then designed the 'Great Britain,' an iron ship, of dimensions far exceeding those of any vessel of its period; and if the first essays were not entirely successful, it must be attributed to the fact of the machinery not having been designed by those whose peculiar study it had been, to produce engines of the class required for such vessels. The disaster in Dundrum Bay demonstrated the scientific design and the practical strength of the hull of the ship, and the successful voyages since made, have proved the correctness of his original views. He was appointed the Consulting Engineer of the Australian Steam Navigation Company, whom he advised to construct vessels of 5,000 tons burthen, to run the entire voyage to Australia, without stopping to coal. His counsels, however, were not followed.

The 'Great Eastern' was his crowning effort, and to the design and execution of this gigantic vessel, far surpassing in dimensions any ship hitherto constructed, he devoted all his energies. The labour was, however, too great for his physical powers, and he broke down under the wearying task; leaving to Mr. John Scott Russell, (M. Inst. C.E.,) and Messrs. Boulton and Watt, his cooperators in the construction of the hull and the engines, the actual completion of the work he had so well and so perseveringly brought up to the day of starting on the trial trip. The disasters attending the launch and the trial trip were unfortunate, but they were, perhaps, inseparable from so novel an experiment, on so gigantic a scale, and the ultimate results may be looked forward to with great interest, as whatever they may be, the impulse given by Mr. Brunel to the construction of large-sized vessels is already felt, and must have great influence both on the mercantile marine and on the Royal Navy.

This sketch of the professional labours of Mr. Brunel is, of necessity, brief and incomplete, nor can the details be given of the

numerous scientific investigations in which he was engaged; but the devotion during two years of considerable portions of his time, to completing the experiments, made by his Father, to test the application of carbonic acid gas, as a motive power for engines, must be mentioned. His special objects of study were mechanical problems connected with railway traction and steam navigation; and although he was not, perhaps, so sound, or so practical a mechanic as his friend, and at the same time, constant opponent, Robert Stephenson, yet his intuitive skill and ready ingenuity enabled him to arrive at satisfactory solutions. The characteristic feature of his works was their size, and his besetting fault was a seeking for novelty, where the adoption of a well-known model would have sufficed. This defect has been unfairly magnified, whenever the pecuniary results of an undertaking have not reached the preconceived standard, and due allowance has not been made for the difficulties encountered in the prosecution of a new and bold enterprise. It might, perhaps, have been as well, if a uniform gauge had been originally established for the United Kingdom,—and such will, doubtless, be the ultimate result,—but not the less must be admired the indomitable energy and consummate skill, with which Mr. Brunel and his coadjutor Mr. C. Saunders, pushed the broad gauge and its tributaries westward to Bristol, Gloucester, and through Wales, to Milford Haven, then south-west to Exeter and Plymouth, and onwards to the Land's End; and after invading the north-west manufacturing district of Birmingham, finally arriving at the shore of the Mersey, opposite to Liverpool. This alone would have sufficed for the lifetime of many men, and in truth, the stupendous labours undertaken by Brunel could not be performed, without overtasking the mental and physical faculties, so that eventually, they must break down.

Mr. Brunel was fervently attached to scientific inquiries; he was a good mathematician and possessed great readiness in the practical application of formulæ. He was elected at an unusually early age, a Fellow of the Royal Society; he received the degree of D.C.L. from the University of Oxford; and he belonged to most of the principal scientific societies of the Metropolis, to several foreign societies, and was a Knight of the Legion of Honour. He was an old Member of the Institution of Civil Engineers, which he joined as an Associate, in January, 1829; he became a Member in 1837, was elected upon the Council in 1845, and was a Vice-President from 1850 up to the time of his death. A liberal patron, as well as a discriminating judge of art, he was himself devoted to artistic pursuits, and his early drawings as well as his professional sketches attest his feeling for purity of design.

Of his private character those only who were admitted to his intimacy, could alone judge correctly. Brunel was not a demonstrative

man, but there was a fund of kindness and goodness within, which only required to be aroused to stand forth in high relief. It has been well said of him by an old friend:—"In youth a more joyous, kind-hearted companion never existed. As a man, always overworked, he was ever ready by advice, and not unfrequently, to a large extent, by his purse, to aid either professional, or private friends. His habitual caution and reserve made many think him cold and worldly, but by those who saw his exterior only, could such an opinion be entertained. His carelessness of contemporary public opinion, and his self-reliance on his own character and that of his works, were carried to a fault. He was never known to court applause. Bold and vigorous professionally, he was as modest and retiring in private life."

Mr. Brunel was present at the trial of the engines, the day before the 'Great Eastern' left the Thames. His health had been failing for some time previously, but on that occasion, he was seized with paralysis. He was immediately conveyed to his home, and after ten days, he expired on the 15th of September, 1859. He was cut off in his fifty-fourth year, just when he had acquired the judgment which, in such a profession as that of the Civil Engineer, can only be attained by long practice and experience, and when the greatest work of his life had reached the very eve of completion. His remains were interred on the 20th of September, in Kensal Green Cemetery, in the presence of his relatives and friends, and of a large number of members of the profession. At a meeting, in November, under the presidency of the Earl of Shelbourne, it was decided, that a public monument should be erected to commemorate his great abilities, and to demonstrate the high esteem in which he was held by his private friends, and his professional brethren.

Mr. HUGH EBRINGTON FORTESCUE, Son of the late Mr. Matthew Fortescue, who, for many years, filled the office of Chamberlain in the Court of his relative, the Earl Fortescue, Viceroy of Ireland, served his pupilage in Civil Engineering under Mr. G. W. Hemans, (M. Inst. C.E.,) and was afterwards employed by that gentleman on the works of the Midland Great Western Railway in Ireland, as Resident Engineer. Being possessed of considerable intelligence and of great energy and skill in field-work, he was afterwards engaged by Mr. Hemans in laying out lines of railway in Spain, and subsequently, in Switzerland, over two ranges of the Alps. In the latter country he also acted, for some time, as District Resident Engineer, under the same gentleman, on the line from the Lake of Zurich to Coire. On leaving Switzerland, he was appointed one of the

assistants to Mr. Doyne, (M. Inst. C.E.,) in the Army Works Corps, in the Crimea, and throughout the many difficulties which beset that corps in its practical working, Mr. Fortescue was remarkable for the efficiency and discipline he maintained among the men committed to his charge. On his return from the Crimea, Mr. Fortescue was employed, with Mr. Bridgeman, (M. Inst. C.E.,) under Mr. Fowler, (M. Inst. C.E.,) in laying out a difficult line of railway in Algeria; and it was chiefly to his labours in that climate, after his previous hard work in the Crimea, that the failure of his health was attributed. His zeal and energy of mind in duties in which he took an interest, led him to make exertions to which his strength was unequal, and in 1859, he fell a victim to consumption, at the early age of thirty-two years. His talents gave great promise for the future, had his life been spared.

He was elected a Member in 1857, but owing to his occupations abroad, he was not able to take any active part in the proceedings, during the short time he was connected with the Institution.

MR. WILLIAM HARTREE was born at Rotherhithe, in December, 1813, and was educated at the Merchant Taylors' School, of which Company he became, subsequently, a liveryman. Having early manifested a decided talent for mechanical pursuits, he became a pupil of Messrs. John Penn and Son, of Greenwich, into which firm, from the abilities and great perseverance he displayed, he was, eventually, admitted a partner, taking, for many years, in that position, a very active and prominent part in the management of those important works, whence have proceeded, not only so many engines for the Royal and mercantile navies of this and other countries, but whence such practical improvements have emanated. Up to within a few days of his decease, he concontinued his active career, and it was after a trying day's service at Devonport, on board H. M. S. 'Windsor Castle,' that on his journey homewards, he laid the seeds for an attack of pleurisy, which terminated fatally, after only a few days' illness. He died on the 8th of February, 1859, in the forty-sixth year of his age, leaving a widow, (the only Sister of Mr. John Penn, (M. Inst. C.E.,) and five children. Not by them alone was his loss deplored, for it was also most sincerely felt by all who had enjoyed the opportunity of appreciating the frankness and kind-heartedness of his character.

He was much devoted to literary pursuits, and had, at an expense of nearly £10,000, collected a fine and well-selected library. Astronomy was also one of his favourite objects of study, and for its prosecution, he erected an observatory at his residence,

near Greenwich. His connection with the Institution dated from 1849, when he was admitted a Member, but his unceasing professional occupations precluded his taking any very active part in the proceedings.

MR. DANIEL MACKAIN was born at Fortrose, Ross-shire, in the year 1800; and, in consequence of his Father having been an Officer of Militia, he, in early life, joined that service. The inactivity of such an occupation led his energetic mind in search of more active pursuits, and, while still a very young man, he devoted himself to the study of Civil Engineering. After filling, for some time, important professional situations in Leith, he was, about the year 1828-29, appointed Engineer and Manager of the Cranston Hill Water Company at Glasgow. Under his able and energetic supervision, the affairs of the company, then at a very low ebb, greatly improved; and on its amalgamation, about twenty years ago, with the Glasgow Water Company, by Act of Parliament, he was appointed sole Engineer. During this period, the arduous and difficult duty of supplying that great and rapidly-increasing city with water, devolved upon him. Considering that the whole supply had to be forced by engine power from a low level, and that the city had greatly exceeded in population, and in the extent of its commerce and manufactures, what was ever contemplated, at the organisation of the works; and recollecting the many imperfections in the old system which modern science had revealed, and of which no one was more thoroughly aware than Mr. Mackain, it must be admitted, that the success of his efforts to supply upwards of 16,000,000 gallons of water per day, required an amount of energy, foresight, and engineering talent of no ordinary kind.

Unobtrusive and quiet, yet self-possessed, he passed through several Parliamentary campaigns, with singular merit and success. In every case in which the water company was either a promoter, or an opponent, Mr. Mackain was the chief engineering witness before the Committees of the House of Commons; and after the fight was over, Counsel on both sides joined in complimenting him, for his calmness, his intelligence, and his integrity. Perhaps the most trying occasion on which he ever appeared, was on his examination as the principal witness in that which was termed 'The Great Arbitration Cause,' when the value of the waterworks was decided, at the time of the plant and undertaking lapsing, under this valuation, into the hands of the city. His conduct and evidence were admitted to be just, honourable, and impartial by both parties in the cause, by the friends he was about to leave, on the one hand, and by the Loch Katrine Water Commissioners

whom he was about to serve, on the other; and the Lord Advocate, (now the Lord Justice Clerk,) who was final umpire in the arbitration, awarded him the highest praise. When the old company meditated the introduction of water by gravitation, Mr. Mackain explored every glen and rill, and tested the capacity of every loch in the West Highlands, and the result of his observations was the Loch Lubnaig scheme. This was not carried out, on account of the difficulty of raising the capital, but there is little doubt, that it would have answered the purpose intended; and it must be looked upon with respect, as the parent of the great Loch Katrine operations now rapidly drawing to a close. About two years ago, Mr. Mackain was invited to proceed to Portugal, which he did with the concurrence of his Directors, to assist in bringing water to the city of Oporto, and the scheme which he recommended is now being carried out.

One of his most prominent characteristics was a conscientious devotion to the interests of his employers and the public, sparing neither bodily fatigue, nor mental exertion, in the fulfilment of his duties. Naturally of a modest and retiring disposition, he was not much known beyond the circle of those with whom his situation brought him in contact; but he had a few friends who knew his genuine worth, admired his talents, his kind and truly unselfish nature, and who will ever revere his memory.

He joined the Institution, as a Member, in 1840, and his death took place at Dalmarnock, on the 8th of February, 1859.

Mr. ROBERT STEPHENSON, the inventor and first constructor of tubular plate-iron bridges, was the only Son of George Stephenson, the 'Father of the Railway System.' He was born on the 16th of October, 1803, at Willington Quay, near Newcastle-upon-Tyne, where his Father was breaksman of a ballast engine. Although Robert Stephenson was born at Willington, he had scarcely any association with the parish, until towards the close of his career, when he contributed a munificent donation to the fund for raising the Stephenson Memorial Schools, which now mark the spot on which stood the home of his Father, and the site of his own birth. Towards the close of 1804, the elder Stephenson removed to Killingworth, a township of Long Benton, and took up his residence at the West Moor Colliery, about five miles from Newcastle.

Having acquired, at the parish school of Long Benton, a rudimentary knowledge of the first elements of education, Robert Stephenson was sent, in 1815, to Mr. Bruce's academy at Newcastle, where he remained during four years, receiving instruction in the usual subjects and in mathematics. On leaving school,

at the midsummer vacation of 1819, he was apprenticed to Mr. Nicholas Wood, (M. Inst. C.E.,) with whom he remained nearly three years, to learn the business of a coal-viewer, and in the performance of his duties, had to inspect the Killingworth colliery, where his father had, several years previously, been the enginewright. He then assisted his Father in the survey for the Stockton and Darlington Railway; and at its completion he was sent, at the close of 1822, to the University of Edinburgh, where for one term, lasting nearly six months, he attended the lectures of the Professors of Mathematics, Chemistry, and Geology. Prizes there were none for him to gain; but he obtained the book which it was the custom of the Mathematical Professor to present, from time to time, to the most meritorious pupil of his class. It was at this period, that he first met, as a class fellow, Mr. George Parker Bidder, (V. P. Inst. C.E.,) with whom, in after years, he was so intimately associated, both professionally and in private life.

Leaving Edinburgh, Robert Stephenson, boy as he was, became the managing partner of the manufactory of engines and machinery of Robert Stephenson and Co., of Newcastle, established in 1823, to meet the demand for locomotive engines which George Stephenson rightly predicted would necessarily ensue, during the course of the next few years. Scarcely, however, was the factory at work, and Robert Stephenson settled in Newcastle, than his health failed, and he accepted an alluring offer, to superintend the working of the gold and silver mines of the Columbian Mining Association, and to report on various engineering works which were, at that time, projected in Columbia. Accordingly, in June, 1824, he left England for South America, where he remained three years, during which time he accomplished his mission with great credit, and he made some investigations and reports which exhibit great foresight and talent. On his way homewards, he visited the United States and Canada, experiencing the perils of shipwreck. It was on this journey that he met with Trevithick, whose splendid dreams of wealth, in Spanish America, had terminated in the stern reality of almost absolute want; and there is little doubt, that the discussions on the steam engine between these original geniuses of such different character, led in the mind of Stephenson, to a closer consideration of the locomotive.

On his arrival in England, in December, 1827, he found the Stockton and Darlington Line in full operation, and the Liverpool and Manchester Railway fast approaching completion. The question as to the best means of traction for the new road was already under discussion, and as the time for opening the line drew near, the controversy amounted to acrimony. Mr. James Walker, (Past-President Inst. C.E.,) and Mr. J. U. Rastrick,

(M. Inst. C.E.), who were employed by the company to investigate the subject, reported, at first, against the adoption of the locomotive so strenuously advocated by Stephenson, and they recommended the use of stationary engines. The Directors, however, determined on giving the locomotive a fair trial, and offered a premium of £500 for that engine which should best fulfil the required conditions. The offer led to the memorable Rainhill contests, at which the 'Rocket,' built by Robert Stephenson, with a boiler on the multitubular principle, suggested by Mr. Henry Booth, and under the guidance of George Stephenson, obtained an easy victory over the other competitors. The success of the 'Rocket' decided the question of locomotive traction. Not content, however, with what he had already achieved, he resolved on effecting further improvements, and the 'Planet,' which virtually gave the type to all succeeding locomotives, was the result of his renewed exertions. From the period of the construction of the 'Rocket,' he still, for several years, persevered in his "endeavours to improve," and such was the success of those efforts, that, as has been justly said by Mr. Nicholas Wood, "to Mr. Robert Stephenson, almost, if not quite, universal assent will be accorded, as having the merit of raising the locomotive engine from what it was in 1829, to what it is in 1860."[1]

Between the close of 1827 and 1833, Robert Stephenson was occupied in railway construction, assisting his Father on the Liverpool and Manchester Railway, and laying down some minor lines. The first great work, however, for the success of which he was solely responsible, was the London and Birmingham Railway, an undertaking of high historic interest, both on account of the gigantic difficulties which were encountered in its construction, and of its being the first public iron road into London. The London and Birmingham Line was opened in 1838, and from that time till the close of his life, Robert Stephenson was engaged in a series of achievements which will hand him down to posterity, as occupying the front rank among Engineers, in an era abounding in men conspicuous for mechanical genius. Important works directed by his counsel, or carried on under his personal superintendence, are to be found in every quarter of the globe. Belgium, Switzerland, Norway, Denmark, Tuscany, Canada, Egypt, and India have lines of railway, formed under his direction.

The works by which he will, probably, be best known to posterity are his bridges;—among them may be mentioned the High Level Bridge at Newcastle-upon-Tyne, the Victoria Bridge at Berwick, the Conway and the Britannia Tubular Bridges on the

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[1] *Vide* "Transactions of the North of England Institute of Mining Engineers," vol. viii., p. 66.

Chester and Holyhead Line, the Victoria Tubular Bridge over the St. Lawrence River at Montreal, and the tubular bridges over the Nile at Benha and at Berket-el-Saba, the precursors of that at Kaffre Azzayat, on the Egyptian Railway from Alexandria to Suez. Such are a few of the principal monuments of his genius. But his Parliamentary services, as a witness in the committee-rooms of the two Houses, were, at the time they were rendered, neither less valuable, nor less distinguished, though, at the present date, they may be less generally known. In the two memorable contests of the Battle of the Gauges, and the Battle of the Atmospheric System, he fought, as he had previously fought in the Battle of the Locomotive,—strenuously, indefatigably, and temperately,—opposing the invincible strength of a calm judgment and lofty intellect, to the brilliant subtleties and splendid daring of a worthy opponent.

Throughout his career, Robert Stephenson was as popular as he was successful. Never ambitious of self-aggrandisement at the expense of his colleagues, he had the rare faculty, inestimable in those who occupy places of chief command, of selecting capable coadjutors and subordinates; and he united to this faculty a generous anxiety, that his assistants should receive the full share of fame and of remuneration due to their exertions. He was consequently, from first to last, an object of affection, not less than of admiration, with the members of his own profession, the contractors, and the men of business with whom he acted. In December, 1837, as the labours of constructing the London and Birmingham Line were being brought to a close, the members of the engineering staff under his command, entertained him at a public dinner at Dunchurch, and presented him with a piece of plate of the value of one hundred and thirty guineas. In the same manner he was, in November, 1839, presented with a service of plate, of the value of twelve hundred and fifty pounds, by the "gentlemen who had been engaged as contractors for the construction of railways, or the supplying of permanent materials." As the subscription of each contributor was limited to five pounds, this demonstration was, in no respect, a mere party movement, but the expression of a general and wide-spread sentiment. On the occasion of the presentation of this testimonial, he was entertained at a very numerously attended public dinner at the Albion Hotel. Besides these and many similar expressions of good-will, unsought honours were poured in upon him. In 1841, he was decorated by the King of the Belgians, with the Order of Leopold; and in 1848, he was presented with the Grand Cross of St. Olaff of Norway. In 1855, the Council of Presidents and Vice-Presidents of the Great French Exhibition awarded to him the Great Gold Medal of Honour, for the invention and introduction of the system

of tubular plate-iron bridges,—First Class Silver Medals being at the same time awarded to Messrs. William Fairbairn, (M. Inst. C.E.,) Eaton Hodgkinson, (Hon. Mem. Inst. C.E.,) and Edwin Clark, (M. Inst. C.E.,) for their respective labours of co-operation,—and he was, at the same time, decorated by the Emperor, with the Order of the Legion of Honour. In 1857, the University of Oxford conferred upon him the Degree of D.C.L. He had also, for several years, been a Fellow of the Royal Society, and he was a Member of most of the other scientific and learned societies of the Metropolis.

His connection with the Institution of Civil Engineers began in 1830, when he became a Member. He was elected a Member of Council in 1845, soon after the first radical change in the constitution of the society, to which he mainly contributed, and he continued in that position till 1848, when he was placed among the Vice-Presidents. At the Annual General Meeting in December, 1855, he was elected President of the Institution, in which capacity he acted during the two ensuing years, 1856 and 1857. It is needless to dilate upon the warm interest he took in everything that concerned the Institution, his assiduous attendance, not only at the Council, but at the Meetings where he so frequently took a prominent part in the discussions, of which the volumes of the Minutes of Proceedings give such instructive evidence. The interest he felt may be said to have continued after his death, for amongst his legacies, he bequeathed the munificent sum of Two Thousand Pounds to that Institution, of which he was so distinguished an ornament.

Entering Parliament in 1847, as Member for Whitby, Robert Stephenson continued to represent that important constituency in the House of Commons, until the period of his decease. A staunch conservative, he voted steadily with his party, but his political conduct was marked by the same generosity that adorned his professional struggles, and the same amiability which endeared him to so many private friends. With the members of all parties he was alike popular, and one of his last acts was to insist on being permitted to subscribe to the testimonial, presented by the liberal members of the House to Sir William Hayter, on his relinquishing the office of 'whip' to their party. In the debates, his voice was not frequently heard; but on the few occasions of his addressing the Speaker, on professional questions, such as that of the Canal of the Isthmus of Suez, and that of the building in Hyde Park for the Great Exhibition of 1851, he was listened to with attention, and acquitted himself with dignity and effect.

A life of severe mental and bodily exertion,—such as that led by Robert Stephenson from early boyhood to the close of his career,—makes decay anticipate old age. For the last eight years

of his existence, his health had, occasionally, manifested symptoms which were calculated to cause great anxiety to his friends. At no time did his mind sustain any loss of vigour; but chronic derangement of the digestive organs indicated the existence of mischief, destined to lay him in the grave, ere he should accomplish the full term of human life. At the beginning of 1859, those symptoms became greatly aggravated, and he was advised to try the effects of change of scene, combined with mental repose. To Robert Stephenson, such a prescription was an impossibility; quiet he could not command. A mind, habituated for nearly half a century to continual action amidst interests, vast, numerous, and diverse, cannot, by an effort of the will, create tranquillity for itself. Moreover, the world would not allow the Engineer that slight amount of rest which he could have commanded, had he been left to shape his own course. Wherever he went, he was followed by those who were anxious for his professional guidance. In September, 1859, however, he broke away from the numerous claimants on his attention, and in his yacht, "that house," as he feelingly described it to a friend, "which has no knockers," made his last voyage to Norway. Yachting was, indeed, the only recreation which he permitted himself, but even then, he combined business with pleasure, performing in that manner his professional visit to several places on the Continent, and to Egypt. At first, he seemed to rally under the refreshing influences of repose and of the sea breezes; but soon the overpowering sense of debility and of depression returned, and the attached friends by whom he was accompanied, justly entertained apprehensions of the worst results. Hastening home from Norway, where he had suffered much, he landed from his yacht at Lowestoft, and was conveyed to London, where he expired at his residence in Gloucester Square, on the 12th of October, 1859, within a few days of completing his fifty-sixth year.

When it is remembered, that Robert Stephenson was a man of varied information, fond of winning others to his opinions, and capable, when he was pleased to make the effort, of writing with singular force and perspicuity, it is a matter of surprise, that he has left behind him very few distinct literary productions. His published Reports on matters connected with his profession are numerous, and well deserving of preservation; but his admirable article on "Iron Bridges," in the Encyclopædia Britannica, is, perhaps, his most important contribution to scientific literature.

On the death of Robert Stephenson, it was felt, that Westminster Abbey was his proper resting-place. An application was made to the authorities for permission to place him in that temple, where the greatest of Britain's chiefs have for centuries been gathered, and the permission was promptly accorded. On the

22nd of October, the funeral was conducted with fitting solemnity, his remains being deposited by the side of Thomas Telford, the first President of the Institution, in the presence of several thousand persons, amongst whom were not only his professional and private friends, but also the most distinguished representatives of the literature, science, and art of Great Britain in the nineteenth century; and among them not an eye was dry, when the last remains of their dear friend and coadjutor disappeared. Shortly afterwards, a public meeting, presided over by Lord Llanover, and attended by a numerous body of noblemen and gentlemen, was held for the purpose of taking into consideration the most appropriate mode of testifying the general respect; when it was resolved, that a statue should be erected to his memory in St. Margaret's Gardens, near the Abbey, where the place of his repose is marked by a monumental brass and a window.

The benevolence which had, in early life, formed a prominent feature of Robert Stephenson's character, manifested itself in his later years, in a series of munificent acts towards the inhabitants of Newcastle and the surrounding district, amongst which may be mentioned, his donation of Twelve Hundred Pounds to the Memorial Schools at Willington Quay, Three Thousand Pounds to the Literary and Philosophical Society, and Ten Thousand Pounds to the General Infirmary of Newcastle. The same spirit of enlightened humanity pervaded his final disposition of the great wealth, which a prudent but liberal management of his private affairs had gathered to his keeping, the provisions of his last will, made a short time previous to his last visit to Norway, conferring upwards of Twenty-five Thousand Pounds on charitable societies and scientific institutions. Few professional men have attained such well-deserved celebrity as Robert Stephenson, and his works will remain to attest his well-earned reputation. His memory will long live in the hearts of those who appreciated and loved him for his manly qualities in private, as they admired him for his public acts and high professional attainments.

MR. THOMAS STOREY, Son of an agriculturist, at Makemerich, near Ponteland, in the County of Northumberland, was born at that place, on the 7th of December, 1789. He received his education at Stamfordham, and served an apprenticeship under Mr. Watson, of Willington, whence he removed into Lancashire, and was employed by Messrs. Clark, Roscoe, and Co., as their Mining Engineer in that county, in Wales, and in Shropshire. In 1822, at the request of Mr. George Stephenson, with whom he was connected by marriage, he was released from his engagement under Messrs. Clark and Co., and was employed in

the construction of the Stockton and Darlington Railway, for which purpose, he removed to St. Helens, Auckland, where he continued to reside until the period of his death. He projected and formed the Great North of England Railway, of which he was the Engineer-in-chief, and on his retirement from that line, he was presented with a splendid dinner service of silver plate. He also projected and formed the Auckland and Weardale Railway, and he was engaged on various other lines.

In person, Mr. Storey was tall and athletic, and capable of undergoing great fatigue. He possessed great decision of character, and was deservedly respected for his strict integrity and honesty of purpose. He was as scrupulously just, as an employer, towards those who served under him, as he had been when an agent, to those under whom he served. During the last few years, he lived in retirement, his health not permitting him to undertake any great public work. He died calmly, after a short illness, on the 15th of October, 1859, in the seventieth year of his age. He had been a Member of the Institution for thirty years, having been elected on the 12th of May, 1829.

MR. ALEXANDER WRIGHT, born in Glasgow in the year 1816, was apprenticed to Mr. Cowan, Gas Engineer of that city. On coming to London, he was engaged at several engineering manufactories; he then conducted the business of Mr. Stevens, (Assoc. Inst. C.E.,) of Southwark Bridge Road; and ultimately, he became principal foreman at Mr. Edge's gas meter manufactory, in Westminster. His engagement under Mr. Edge terminating in 1844, he established himself as a meter manufacturer, at Hamburg, but not being so successful as he anticipated, he returned to London and carried on the manufacture of meters and gas apparatus, for a short time, in Holywell Street, and afterwards, in Millbank Street, Westminster. During this period, Mr. Wright sedulously devoted himself to chemistry and to the practical details of gas engineering; he built several gas works, and constructed the largest station meter then made. He also invented several instruments for testing the quality of gas, equally adapted to the requirements of the practical gas manufacturer and to those of the scientific experimentalist, among which may be mentioned, an improved apparatus for determining the specific gravity of coal gas, and an instrument for detecting the quantity of bisulphuret of carbon; an alkalimeter, adapted for readily ascertaining the strength of ammoniacal liquor; a registering pressure-gauge for supply mains and for exhausters, &c. He also materially assisted in putting the Bunsen photometer into a working form, and in establishing correct principles for photo-

metric investigations. Mr. Wright had thus attained considerable celebrity as a practical Engineer and careful analyst. He contributed some able articles to the "Journal of Gas Lighting," the most important of which were;—"The Theory and Economy of Artificial Light;"[1] "Coal and its Products by Distillation;"[2] and "The History of the Gas Meter."[3] Unfortunately, however, engagements led him to defer the conclusion of the last, from time to time, and it remains unfinished.

In 1850, Mr. Wright accepted the appointment of Engineer to the Western Gas Light Company, which owes much of its success and present prosperous condition to his indomitable resolution, industry, and judgment. In 1857, he was also appointed Consulting Engineer to the Great Central Gas Consumers' Company, which appointment, from peculiar circumstances affecting that company at the time, offered considerable scope for the exercise of his talents and energies. He continued to discharge his duties to the satisfaction of the directors and shareholders of these two companies, to the time of his death.

Mr. Wright originated and patented, in 1856, a plan for lighting mines with gas. This scheme was successfully carried into operation at the Balleswidden Mine, St. Just, Cornwall, but unfortunately, soon after its practicability had been demonstrated, the mine proved unprofitable to the adventurers, and was almost entirely closed; this threw a damp on the project, and it has since remained in abeyance.

The Metropolitan Local Management Act came into operation in the year 1855, and Mr. Wright was elected Member of the Board of Works, for the Westminster district, which position he continued to hold to the date of his death, having been re-elected in June, 1859.

The following remarks from the "Journal of Gas Lighting,"[4] will express the estimation in which Mr. Wright was held by the members of his profession:—

"Cut off at the premature age of forty-three, in the prime of life, in robust health, and in the flood-tide of that prosperity which his unwearied industry, his conciliating manners, his vigorous intellect, his unimpeached integrity, and his enlarged views had justly won for him. His loss leaves a blank in a large circle, the extent of which can only be appreciated by those who knew him as well, and appreciated him as sincerely, as the writer of these lines; and it is no disgrace to his brethren who survive him to say, that the blank is one which will not be easily filled up. Alexander Wright was, indeed, an honour to his country and his profession. A self-taught genius, he combined acuteness of perception with

[1] *Vide* "Journal of Gas Lighting," vol. i., p. 75, *et seq.*
[2] *Ibid.*, vol. i., pp. 12 and 69.
[3] *Ibid.*, vol. i., p. 114, *et seq.*
[4] *Ibid.*, 2nd of August, 1859, p. 418.

quickness of apprehension; a singular felicity in expressing his views, with the most varied knowledge on scientific subjects; and modesty of demeanour with a frankness and candour which impressed those around him with confidence in his judgment. His contributions to the perfecting of the gas meter were many and important, and his paper on "The History of the Gas Meter," which appeared anonymously in our columns some years since, proves how thoroughly he understood that subject. His self-registering pressure indicator is to be found in every well-regulated gas-work throughout the land, and his photometers, in experienced hands, have relieved photometry from the doubts which empiricism threw over its early practice. As a member of the Metropolitan Board of Works, he entered upon another sphere of usefulness, in which the soundness of his views on the subject of metropolitan improvement soon placed him in the front rank among the members of that body. The main drainage scheme was carried through the opposition it encountered principally by his indomitable perseverance, and he looked forward to the embankment of the Thames as the next great work of the Board.

"Towards the latter end of June Mr. Wright sought relaxation from his labours by a journey in the north of Europe. He returned from Hamburg on the 17th of July, and on the following day was seized with an attack of Asiatic cholera in its most malignant form, to which he finally succumbed on the 23rd. He was interred near two of his children in the Norwood Cemetery on the 27th, amidst the mournful regret of the numerous friends who had assembled round his grave to pay the last honours to departed worth; and if anything can soothe the sorrow of his family on so trying an occasion, the universal expression of affection for his memory which their bereavement has called forth, is not without value."

Mr. Wright was admitted an Associate of the Institution in 1856, and was transferred to the class of Members, on the 25th of January, 1859, only six months before his death, which occnrred on the 23rd of July, 1859.

MR. JAMES BARRETT was born in Queen Square, Bristol, in the year 1808, and was educated at Brislington, near that city. At an early age he entered the office of the late Mr. H. C. Price, who had introduced a new system of warming and ventilating, known as that of Price and Manby, and Mr. Barrett took an active part for many years, in the application of the system to the numerous buildings in which it has been employed. In 1848, Mr. Barrett became acquainted with the late Dr. Henry Hawes Fox, of Bristol, who had recently originated a method of fire-proof construction now well known as 'Fox and Barrett's'; and, in conjunction with the eldest son of Dr. Fox, he removed to London and established the system which has since been so extensively adopted, and with which his name will always be identified. Dr. Fox dying in 1851, the partnership was dissolved, and from that time, the business was carried on by Mr. Barrett, with the assistance of his Son.

He joined the Institution, as an Associate, in 1850, and was a

frequent attendant at the Meetings. In January, 1853, he contributed a Paper[1] "On the Construction of Fire-proof Buildings," to which a Telford Medal was awarded. His decease, due to an attack of erysipelas in the head, occurred very suddenly on the 30th of April, 1859, in his fifty-first year, to the great grief of his family and of a numerous circle of friends, by whom he was justly esteemed as a very worthy, upright man.

Mr. SAMUEL BENNETT was practically educated as a Mechanical Engineer, and at an early age, was employed under his Brother-in-law, the late Mr. Roentgen, (M. Inst. C.E.,) in the extensive ship-building yards and steam-engine manufactory opposite to Rotterdam, where he was actively engaged, for many years, in the construction of steamboats, both for sea and river navigation, of sugar mills, and of other machinery. He subsequently removed to Batavia, to take the management of a branch establishment, for repairing machinery, where he died in the year 1859.

He joined the Institution as an Associate, in 1839, but he was precluded, by his constant residence abroad, from taking any active part in the proceedings.

Mr. ROBERT CANTWELL was brought up with his Father, who was the founder of the Surveyors' Club, still in existence to the present day, and who, after having realised a handsome fortune, retired from practice many years before his death. The business of an Architect and Surveyor, carried on by Mr. Robert Cantwell, although extensive, was for the most part, of so private a nature as to afford but little material for a memoir of his professional life. He did not hold any public appointments, nor did he execute any important works. His practical knowledge, however, was great, and his integrity was so well known, that he was largely employed in the settlement, by arbitration, of disputed claims. He was, at one period, much engaged upon parochial assessments, and was one of the pioneers of modern views upon the subject. In the course of his practice, he became acquainted with many of the leading Engineers of his day, and ultimately, he joined the Institution as an Associate in 1841. He died in 1859, aged sixty-six years, at his residence in Wimpole Street, London, much respected both by his professional brethren, and by his private friends.

Mr. GEORGE GARDNER DONALDSON was born on the 22nd of May, 1801, at Nemphlar, near Lanark, where he

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xii., page 244.

received a sound English and mathematical education. In early life he devoted himself, for some years, with great success to the cultivation of his Father's farm, an occupation very suitable to his taste and talents. He left Scotland in 1835, for Dartmouth, Devon, where he had been appointed land steward to Colonel Seale. He was, however, disappointed in his expectations, and removed, after a short time, to Lancaster, to take charge of some large estates at Wyersdale, belonging to Mr. Garnett, M.P. Whilst there, he published a pamphlet on land drainage, which had a large circulation in the neighbourhood. He afterwards came to London, and was intrusted by the London and North Western Railway Company, with the charge of their landed property between London and Birmingham. He was next employed, during several years, in assisting the late Mr. James Smith, of Deanston, in valuations and land drainage, and in other matters connected with practical engineering. So high an opinion did Mr. Smith entertain of his skill, that he intrusted him with the entire management of the drainage of Sir Robert Peel's estates at Tamworth, and also of those at Castle Ashby, the seat of the Marquis of Northampton. He afterwards became one of the Surveyors under the Metropolitan Commissioners of Sewers, in which capacity the execution of important and difficult works devolved upon him. At the expiration of the Commission, he became Surveyor to the British Land Company, in whose service he died of diphtheria, on the 20th of November, 1859, at the age of fifty-eight years, within a week after his return from surveying an estate in a marsh near the Forest of Dean. His remains were deposited in the cemetery at Norwood, and although they were followed to the grave by few, they were sincere mourners. He has left a widow, by whom his loss is bitterly deplored.

Mr. Donaldson was a man of strict integrity and prompt judgment; and his urbanity and courtesy of manner caused him to be loved by his private friends, and respected by all those with whom he was associated in public life. Many of those who worked with him in a subordinate position, testify to his great kindness of heart, to his conscientiousness in upholding them from injustice, and to his taking every opportunity of promoting the interests of the deserving.

He was elected an Associate of the Institution, in 1856, and was a frequent attendant at the Meetings, occasionally offering remarks when the subject of the discussions in any way related to agriculture, or drainage. He also presented, in 1851, an interesting Paper,[1] descriptive of works at Richmond, designed by him, and of which he superintended the execution.

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xi., p. 407.

Mr. ROBERT BARLOW GARDINER, of the Island of Jamaica, began professional life as a pupil of Mr. Tress, the Architect and Surveyor, after which he practised on his own account, for six years, in the Metropolis. He then took charge, under Mr. P. W. Barlow, (M. Inst. C.E.,) of the station buildings and goods warehouses on the South Eastern Railway, for four years; and during the next two years and a half, for Messrs. Jackson, Brassey, and Henfrey, of the building works on the Turin and Susa Railway. He afterwards became, for a short time, a manager for the contractor, on the Pernambuco Line. He was also employed, under Mr. Fowler, (M. Inst. C.E.,) on the surveys of the Great Northern Railway of Portugal. He recently left England for Jamaica, where he was appointed Architect and Engineer for the County of Middlesex, and Commissioner of Roads and Bridges in that island. He died at Spanish Town, on the 14th of June, 1859, at the age of forty-one years, having been an Associate of the Institution only six months.

Mr. EDWARD HIGHTON was born on the 13th of August, 1817, at Leicester, at which town he received a classical and mathematical education, first at the grammar school, and afterwards from a private tutor, the Reverend John Foster, of St. Mary's. He then became the pupil of Mr. Stephen Robinson, (M. Inst. C.E.,) of Durham, the Engineer to the Hartlepool Dock and Railway Company. After completing his professional education, and on the contractors failing to perform the excavations required, he was intrusted with the management of the works, and as Assistant Engineer, he superintended, during upwards of three years, the construction of the docks on behalf of the Company. In 1845, he was appointed Resident Engineer of the Taff Vale Dock and Railway; and in 1846, he became Telegraphic Engineer to the London and North Western Railway Company, having, in conjunction with his Brother, devoted himself to the especial study of electric telegraphy, and contributing the whole of the mechanical details and many of the principles of the several patents taken out by them. He read several Papers before the Society of Arts,[1] and he took part in the discussions upon telegraphic subjects at the Meetings of the Institution of Civil Engineers, which he had joined as an Associate, in 1847. In 1849, he received the large gold medal of the Society of Arts, for his inventions in electric telegraphy, for which he also, subsequently, received another medal at the Great Exhibition of 1851. Several of his inventions are still in use by

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[1] One of these, 'On Atmospheric Electricity, was published in the "Transactions of the Society of Arts." Supplemental Volume. 4to. London, 1852. Pages 85–112

the British and Irish Magnetic Telegraph Company, who are the owners of the patents.

He was, latterly, compelled to retire from the active duties of his profession, on account of his declining health, which had been much injured by his professional labours and anxieties. He died on the 13th of November, 1859, at the age of forty-two years, greatly beloved by his relatives, to many of whom he had almost acted the part of a father, and towards whom he had always shown the most kind and generous disposition.

He was the author of some poetry of considerable merit, which, however, was only printed for private distribution. He contributed the work on the electric telegraph, published in Weale's Series.[1]

MR. JOHN HOULDSWORTH, of Cranston Hill, was born at Whitehall, Glasgow, on the 12th of April, 1807. His Father, the late Henry Houldsworth, of Coltness, Lanarkshire, removed with his Brother-in-law, Mr. William Hussey, upwards of sixty years ago, from Lancashire to Glasgow, where he introduced many improvements in the spinning of cotton, and gave a fresh impetus to what was then a small, but is now a great branch of manufacture in the commercial metropolis of Scotland.

The subject of this memoir received the best education which the institutions of his native city afforded; and when about eighteen years of age, he was sent abroad. He resided in Geneva for upwards of two years, and his being thus early thrown among strangers and new objects, had great effect in developing a liberal and highly scientific mind. On his return to Glasgow, he undertook the partial management of his father's mechanical business, and his natural taste for that profession soon led him to take the foremost rank among the skilled men of the time. He was a very intimate friend and associate of the late Mr. James Smith, of Deanston, with whom he was connected in bringing out some valuable and important improvements in the spinning of cotton. It should also be mentioned, that some years ago, Sir Peter Fairbairn was connected with him in business. About twenty-five years ago, Mr. Houldsworth gave his earnest attention to the development of some of the extensive fields of iron ore in the west of Scotland, and with his Brothers, and some friends of his family, he established the Coltness and Dalmellington Ironworks, situated in Lanarkshire and Ayrshire, in which counties the proprietors have now fourteen blast furnaces, capable of producing about 120,000 tons of pig iron annually. He was, in addition, the senior partner of various establishments for machine making, iron founding, cotton spinning and weaving; all of which were in

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[1] *Vide* "The Electric Telegraph; its History and Progress." By Edward Highton. 8vo. London, 1852; p. 179.

a flourishing condition, and gave employment to great numbers of people. He was likewise connected with several large railway undertakings, and with shipping; his services as a Director having been found very valuable, in consequence of his great experience in business, added to his scientific attainments and general intelligence. He never failed to lend a helping hand to establish any great national, or local enterprise, or to give advice as well as pecuniary assistance, if necessary, to individual genius. His practical and scientific information rendered his advice and judgment of the greatest importance, and his evidence before Committees of the House of Commons, and in legal courts, was of the highest value; in no case was this more remarkable, than during the celebrated 'Hot Blast Trial.'

Only four months before his death, he returned from an excursion to Norway, whither he had gone in his yacht, with a few friends. It is remarkable, that from that time, he, like the late Mr. Robert Stephenson, who made the same voyage about the same period, and under the same circumstances, never enjoyed his wonted health. The weather being exceedingly boisterous, was, probably, instrumental in aggravating, in both cases, diseases, which resulted in depriving society of two valuable members. After a short illness, he died at Glasgow, from a severe attack of liver complaint, on the 18th of October, 1859, in the fifty-third year of his age; and no citizen in a public, or private capacity could be more regretted, not only by the large circle of relatives and intimate friends who enjoyed his munificent hospitality, but by the general public, who fully appreciated the benevolence of his character and the exemplary utility of his life.

He was the last Provost of the Burgh of Anderston, before it was incorporated with the municipality of Glasgow, and at his decease, he was the senior magistrate of the latter city. He had been connected with the Institution of Civil Engineers fifteen years, having joined it as an Associate, in 1844.

MR. EDWARD HUGHES was born in Ireland, in 1819; and after receiving the rudiments of education at the Kildare Place Model School, Dublin, he became, in 1836, through the recommendation of Mr. Irvine, the master of the Kildare School, the junior teacher of writing and arithmetic in the Clergy Sons' School at Edgworthstown. He was, subsequently, through the same influence, appointed, in 1839, to Aubyn's Pauper Model School, at Norwood, then under the superintendence of the Committee of Council on Education. In 1841, Mr. Hughes was named second master of the Lower School of Greenwich Hospital; and in 1844, he succeeded to the office of Head Master of the Royal Naval School, on the retirement of his friend, Mr. Irvine, to

whose care he had, from his earliest boyhood, owed much of his success. While at Greenwich, Mr. Hughes edited and compiled several elementary educational books, principally on geography and arithmetic. Expenses attending the publication of some of his later works, exhausted his means, and greatly harassed and distressed him. His health failed; and after a lingering illness, he died at Greenwich Hospital, on the 30th of July, 1859, in the fortieth year of his age, leaving a very large family in embarrassed circumstances. His mathematical and mechanical attainments led to his election, in 1848, as an Associate of the Institution.

MR. GEORGE MILLS was born in 1796, in London, where he served his apprenticeship to an ironmonger, smith, and stovemaker, with whom he afterwards remained some time as a workman. About the year 1821, he became foreman at a similar establishment; and, in 1827, he undertook the management of a business in Bond Street. He had always a great desire to learn engineering, and between the last two periods, he attended evening classes, in order to acquire a knowledge of mensuration and of mechanical drawing. After a diligent study of many of the engineering works then in progress, he, in 1830, commenced business on his own account, in Warwick Street, as a Mechanical Engineer. Shortly afterwards, he was introduced to Mr. Trevithick, the well-known Engineer, with whom, eventually, he entered into a partnership, which was, however, soon dissolved, in consequence of over-speculation, and of Mr. Trevithick not obtaining from abroad, the remittances which he had expected. He next became the partner of Mr. Dyett, with whom he established an iron foundry at Birmingham, commencing by the construction of engines for the 'Shakspeare,' a vessel which was afterwards sent out to Rio de Janeiro. At this period, Messrs. Mills and Dyett were allowed, for some time, the use of a Government vessel, the 'Falcon,' in which to try their engines. The business not proving successful, the partnership was dissolved, and, in 1839, Mr. Mills returned to London, where he soon afterwards obtained the appointments of Superintendent Engineer of the Herne Bay Steam Packet Company, and of the Thames Steam Towing Company. In 1842, he was appointed Superintendent Engineer of the West India Royal Mail Packet Company, and he removed to Southampton, where he formed an establishment for the repair of the company's fleet. During his connection with this company he displayed considerable energy and ability, and untiring zeal and perseverance in carrying out the service, particularly in the punctual performance of the mail contracts, under

the many disasters which happened to the company, by the loss of so many of their ships. He took great interest in the welfare of marine engineers, and endeavoured, in every way, to advance the interests of those serving afloat. He strongly advocated the introduction of superheated steam; and after the trials of Mr. Wethered's combined steam in the 'Black Eagle' and the 'Dee,' he associated himself with that gentleman, and caused his system to be applied to the company's steamer 'Avon.' That he did so successfully, is proved by the fact, that no better results, as to economy, have been arrived at, from the subsequent use of superheated steam alone, or of combined steam, than those shown by the performances of the 'Avon.' He remained in the service of the company until June, 1857, when he resigned upon a superannuation allowance of £500 per annum, which he did not live long to enjoy. His health had been for some time declining, and he died at Southampton, after a painful illness, on the 17th of January, 1859, in the sixty-third year of his age. After his retirement, he became Chairman of the Risca Iron and Coal Company, in which undertaking he unfortunately invested nearly the whole of his property; and the ample means which, he imagined, he had left to his widow, were almost entirely sacrificed by the failure of the company, one year after his death. He was intimately acquainted with most of the manufacturing engineers and shipbuilders of England, by whom he was greatly esteemed for his strict integrity and his urbanity of manner. He joined the Institution as an Associate, in 1843.

[PREMIUMS

PREMIUMS AWARDED.

Session 1858-59.

The Council of the Institution of Civil Engineers have awarded the following Premiums:—

1. A Telford Medal, to Michael Scott, M. Inst. C.E., for his Paper, "Description of a Breakwater at the Port of Blyth; and of Improvements in Breakwaters, applicable to Harbours of Refuge."
2. A Telford Medal, to Robert Mallet, M. Inst. C.E., for his Paper, "On the Coefficients, T_e and T_r, of Elasticity and of Rupture in Wrought Iron, in relation to the volume of the Metallic Mass, its Metallurgic Treatment, and the Axial Direction of its constituent crystals."
3. A Telford Medal, to Henry Bessemer, for his Paper, "On the Manufacture of Malleable Iron and Steel."
4. A Telford Medal, and the Manby Premium, in Books, to William Joseph Kingsbury, Assoc. Inst. C.E., for his Paper, "Description of the Entrance, Entrance Lock, and Jetty Walls of the Victoria (London) Docks; with a detailed account of the Wrought-Iron Gates and Caisson, and remarks upon the form adopted in their construction."
5. A Watt Medal, to James Wardrop Jameson, Assoc. Inst. C.E., for his Paper, "On the Performances of the Screw Steam-Ship 'Sahel,' fitted with Du Trembley's Combined-Vapour Engine, and of the sister ship 'Oasis,' fitted with Steam Engines worked expansively, and provided with partial Surface Condensation."
6. A Council Premium of Books to Thomas Sebastian Isaac, for his Paper, "On the use of Locomotive Power, on Gradients of 1 in 17, and Curves of 300 feet radius, on Railways in America."
7. A Council Premium of Books to Matthew Bullock Jackson, M. Inst. C.E., for his Paper, "On the Water Supply to the City of Melbourne, South Australia; comprising a brief description of the Melbourne Gravitation Waterworks."

[Subjects

SUBJECTS FOR PREMIUMS.

Session 1859-60.

The Council invite communications on the following, as well as other subjects, for Premiums:—

1. A Review of the Plans which have been proposed, at different times, for the Embankment of the River Thames.
2. On the Principles upon which the Works for the Improvement of River Navigation should be conducted, and the Effects of the works upon the Drainage and Irrigation of the District; including accounts of the Systems of Moveable Dams, ('Barrages Mobiles,') in Rivers on the Continent.
3. On the Effect of Engineering Works in causing injurious Scour, Flooding, or Silting-up, in Tidal Estuaries, or Rivers.
4. On the Main Natural and Artificial Drains of the Country, the extent to which they have been affected by the increasing amount of Agricultural Land Drainage, and the general influence upon the Main River Outfalls.
5. On Reclaiming Land from Seas and Estuaries.
6. On the Results of the Employment of Steam Tugs on Canals, and of other measures for the Improvement of Canals, as a means of conveyance for heavy traffic.
7. On the Methods of constructing Foundations, for large Structures, in deep water.
8. Description of Cast, or Wrought-Iron Cranes, Scaffolding, and Machinery, employed in large works, in Stone Quarries, Hoists, or Lifts on Quays, in Warehouses, etc., especially where either Steam, or Water is used as a motive power.
9. On the Results of Experiments on the Crushing Weights of different materials, particularly as to the resisting powers of Rubble Masonry, set in different limes and cements.
10. The Selection of Sites for the Construction of Docks on the course of Tidal Streams, with reference to communication with Railways, and with Inland Navigation.
11. The Selection of Sites for, and the Principles of, the Construction of Breakwaters, Harbours of Refuge, Piers, Moles, (whether solid, or on arches), Sea Walls, and Shore Defences; illustrated by examples of known constructions.

12. The Construction of Lighthouses; their Machinery and Lighting Apparatus; with notices of the methods in use for distinguishing the different Lights.
13. On the Mechanical Methods of Boring and of Sinking large Shafts, of introducing the Tubbing and the impervious lining, and of traversing running sand, and other difficult strata.
14. The Results of Contrivances for facilitating the Driving of Tunnels, or Drifts in Rock.
15. The Results of a series of Observations on the Flow of Water from the Ground, in any large district; with accurately-recorded Rain-Gauge Registries, in the same locality, for a period of not less than twelve months.
16. On the Construction of Catchwater Reservoirs in Mountain Districts, for the Supply of Towns, or for Manufacturing purposes.
17. Accounts of existing Waterworks; showing the Methods of Supply, the Distribution throughout the Streets of Towns, and the general practical results.
18. The Comparative Duty performed by, and Improvements in the Construction of, modern Pumping Engines for raising Water, for the Supply of Towns, or for the Drainage of Mines; noticing in the latter cases, the depth and length of the underground workings, the height of the surface above the sea, the geological formation, the contiguity of streams, &c.
19. The Results of the use of Bucket and Rotary Pumps, for lifting large quantities of water to a limited height; as at the Haarlem Meer, or at Whittlesea Mere: with Descriptions of the Machinery employed, and the application of such machinery to the raising of the Sewage of Large Towns.
20. On the Methods in use in various countries, for Raising Water for the purposes of Irrigation.
21. The Drainage and Sewerage of Large Towns; exemplified by accounts of the systems at present pursued, with regard to the level and position of the outfall, the form, dimensions, and material of the sewers, the prevention of emanations from them, the arrangements for connecting the house drains with the public sewers, and the disposal of the sewage, whether in a liquid form, as irrigation, or in a solid form after deodorisation.
22. On Boiler Inspection as practised in this country and on the Continent, with remarks as to the comparative merits of the two systems.
23. On the most Recent Systems of Smoke Prevention, in Stationary, Marine, and Locomotive Boilers; and a discussion of the existing difficulties.

24. On the Causes of the alleged Failure in Economising Fuel, in working Steam expansively, and the probable conditions for insuring success.
25. On the Results of the use of Superheated Steam.
26. On Substitutes for Steam, and the Causes of their Failure.
27. On the Results of the use of Tubular Boilers, and of Steam at an increased pressure, for Marine and other Engines, noticing, particularly, the difference in Weight and in Speed, in proportion to the Horse Power and the Tonnage.
28. On the Best Methods of Reducing the Temperature of the Engine and Boiler Room of Steam Vessels, and of preventing the danger arising from the over-heating of the base of the funnel.
29. The Substitution of Machinery for Manual Labour, for Raising, Lowering, and Reefing the Sails, Weighing the Anchor, &c., on board ship.
30. On Steam Vessels of Light Draught for the Shallow Rivers of India, &c.
31. Description of the 'Great Eastern' Steamer, and of the results of the trial voyages.
32. On the Form and Materials for Floating Batteries, ('Vaisseau bélier'), and the points requiring attention in their Construction.
33. On the Ascertained Duration, and other qualities, of the numerous systems of Permanent Way in use in England and in other countries, with their original Cost and expense of Maintenance.
34. Improvements in the Construction of Railway Carriages and Waggons, with a view to the reduction of the gross weight of Passenger Trains; also of Railway Wheels, Axles, Bearings, Axle Boxes, and Breaks, and of Bearing, Traction, and Buffer Springs; treating particularly of their ascertained duration and their relative friction.
35. Descriptions of the various kinds of Machinery in use in the principal Shipping Ports for the Shipment of Coal; noticing particularly, those in which the greatest expedition is combined with the least amount of breakage of the coal; and also accounts of the means of unshipping and measuring, or weighing the coal, on its arrival in port.
36. On the means of Utilising the products of the Distillation of Coal, so as to make Coke commercially as cheap as Coal; with descriptions of the Ovens, and of the best processes used in Great Britain and on the Continent, in the Manufacture of Coke.
37. The Precautions adopted for guarding against Accidents by Fire-damp and After-damp in Mines.

38. The most Effective Arrangement and Form of Centrifugal and Reciprocating Blowing Apparatus.
39. The Chemical Analysis, and the Application to economic purposes, of the Gases generated in Iron Blast-Furnaces.
40. Description of Modifications of the present systems of Smelting Iron Ores, of Improvements in the Conversion of Cast Iron into the malleable state, and of the Manufacture of Iron generally, comprising the distribution and management of Ironworks.
41. An Investigation of the Causes of Red and of Cold Shortness in Malleable Iron, and other Chemical Characteristics which affect the Physical Properties of Cast, or of Wrought Iron.
42. Improvements in the Manufacture of Iron for Rails and Wheel Tyres, having special reference to the increased capability of resisting lamination and abrasion; and accounts of the Machinery required for rolling heavy Rails, Shafts, and Bars of Iron of large sectional area.
43. On the use of Steel Bars and Plates in Enginework and Machinery, for Boilers and for Ship-Building.
44. The Process of Manufacture, and mode of treatment, of Aluminium.
45. On the Importance of Balancing the Rotating, or Alternating parts of Machinery.
46. On the Forms and Dimensions of Journals of Machine Shafts, Axles, &c.; with the best Composition for the linings of Bearings, and the most approved methods of Lubricating.
47. On the Mechanism of Astronomical Instruments, with suggestions for its improvement.
48. On Machinery adapted for the better Separation of the various substances found in combination with Metallic Productions.
49. On Machinery for Crushing Ores.
50. On the Substitution of Machinery for Manual Labour in Mining Operations; and on Hydraulic Machinery in Mines.
51. On the Improvements which may be effected in the Buildings, Machinery, and Apparatus for producing Sugar from the Cane in the Plantations and Sugarworks of the British Colonies, and the Comparison with Beet Root, with regard to quantity, quality, and economy of manufacture.
52. Accounts of the Improved Systems of Storing, Cleansing, and Drying Corn, and of producing Flour.
53. Description of the Machinery adapted for the Preparation of Indian Cotton.
54. Improvements in Flax Machinery, and in the processes for preparing the Flax for manipulation.

55. The uses of Vulcanised, or Mineralised Caoutchouc; the means of increasing its durability, and the modes of causing its adhesion to Metal.
56. On the Application of Photography to Engineering.
57. The Construction of Clocks to be moved simultaneously by the agency of Galvanic Electricity.
58. On the Form and Construction of Submarine Telegraph Cables, most suitable for certain specified depths; and an investigation into the nature of any new substances adapted for the insulating medium.
59. Memoirs and Accounts of the Works and Inventions of any of the following Engineers:—Sir Hugh Middleton, Arthur Woolf, Jonathan Hornblower, Richard Trevithick, William Murdoch (of Soho), Alexander Nimmo, and John Rennie.

Original Papers, Reports, or Designs, of these, or other eminent individuals, are particularly valuable for the Library of the Institution.

The communications must be forwarded, on or before the 30th of January, 1860, to the house of the Institution, No. 25, Great George Street, Westminster, S.W., where copies of this Paper, and any further information may be obtained.

CHARLES MANBY, *Secretary.*

25, *Great George Street, Westminster, S. W.,*
October, 1859.

NOTICE.

It has frequently occurred, that in Papers which have been considered deserving of being read and published, and have even had Premiums awarded to them, the Authors may have advanced somewhat doubtful theories, or may have arrived at conclusions at variance with received opinions. The Council would, therefore, emphatically repeat, that the Institution must not, as a body, be considered responsible for the facts and opinions advanced in the Papers, or in the consequent Discussions; and it must be understood, that such Papers may have Medals and Premiums awarded to them, on account of the Science, Talent, or Industry displayed in the consideration of the subject, and for the good which may be expected to result from the discussion and the inquiry; but that such notice, or award, must not be considered as any expression of opinion, on the part of the Institution, of the correctness of any of the views entertained by the Authors of the Papers.

EXTRACTS FROM THE MINUTES OF COUNCIL, FEB. 23rd, 1835.

"The principal subjects for which Premiums will be given are:—

"1st. Descriptions, accompanied by Plans and explanatory Drawings, of any work in Civil Engineering, as far as absolutely executed; and which shall contain authentic details of the progress of the work. (Smeaton's Account of the Edystone Lighthouse may be taken as an example.)

"2ndly. Models, or Drawings, with descriptions of useful Engines and Machines; Plans of Harbours, Bridges, Roads, Rivers, Canals, Mines, &c.; Surveys and Sections of Districts of Country.

"3rdly. Practical Essays on subjects connected with Civil Engineering, such as Geology, Mineralogy, Chemistry, Physics, Mechanic Arts, Statistics, Agriculture, &c.; together with Models, Drawings, or Descriptions of any new and useful Apparatus, or Instruments applicable to the purposes of Engineering, or Surveying."

EXCERPT BYE LAWS, SECTION XIV., CLAUSE 3.

"Every Paper, Map, Plan, Drawing, or Model presented to the Institution, shall be considered the property thereof, unless there shall have been some previous arrangement to the contrary; and the Council may publish the same, in any way and at any time they may think proper. But should the Council refuse, or delay the publication of such Paper, beyond a reasonable time, the Author thereof shall have a right to copy the same, and to publish it as he may think fit, having previously given notice, in writing, to the Secretary, of his intention. No person shall publish, or give his consent for the publication of any communication presented and belonging to the Institution, without the previous consent of the Council."

INSTRUCTIONS FOR PREPARING COMMUNICATIONS.

The Communications should be written in the impersonal pronoun, and be legibly transcribed on foolscap paper, about thirteen inches by eight inches, the lines being three-quarters of an inch apart, on the one side only, leaving a margin of one inch and a-half in width on the left side, in order that the sheets may be bound.

The Drawings should be on mounted paper, and with as many details as may be necessary to illustrate the subject, and should be to such a scale that they may be clearly visible, when suspended on the walls of the Theatre of the Institution, at the time of reading the communication; or enlarged Diagrams may be sent for the illustration of any particular portions.

Reduced Drawings for the illustrative Plates and Woodcuts will be required, as soon as the Papers are accepted.

Papers which have been read at the Meetings of other Scientific Societies, or have been published in any form, cannot be read at a Meeting of the Institution, nor be admitted to competition for the Premiums.

[ORIGINAL

ORIGINAL COMMUNICATIONS,

DRAWINGS, PRESENTS, &c.,

RECEIVED BETWEEN JUNE 30, 1858, AND JUNE 29, 1859.

ORIGINAL COMMUNICATIONS.

AUTHORS.

Amos, C. E. No. 1,002.—On the Government Waterworks in Trafalgar Square.

Bessemer, H. No. 1,012.—On the Manufacture of Malleable Iron and Steel. With a series of Diagrams.

Blake, J. No. 996.—On the Construction of Catchwater Reservoirs in Mountain Districts, for the Supply of Towns, and for Manufacturing purposes.

Brussaut, P. A. de. No. 1,001.—On a New System of Axle Boxes, not requiring Lubrication, and without Liability to Heating. With a series of Diagrams.

Chadwick, D. No. 1,008.—On Improvements in High-Pressure Water Meters.

Grantham, R. B. No. 1,005.—On Arterial Drainage and Outfalls. With a series of Diagrams.

Harrison, T. E. No. 1,011.—On the Tyne Docks at South Shields; and the mode adopted for Shipping Coals. With a series of Drawings and Diagrams.

Isaac, T. S. No. 990.—On the use of Locomotive Power, on Gradients of 1 in 17, and Curves of 300 feet radius, on Railways in America. With a Diagram, Plan, and Section of the Virginia Central Railroad.

James, Jabez. No. 1,000.—On the Process of Raising and Hanging the Bells in the Clock Tower at the New Palace, Westminster. With a series of Diagrams.

Jameson, J. W. No. 993.—On the Performances of the Screw Steam-Ship 'Sahel,' fitted with Du Trembley's Combined-Vapour Engine, and of the sister ship 'Oasis,' fitted with Steam Engines worked expansively, and provided with partial Surface Condensation. With a series of Drawings and Diagrams.

AUTHORS.

Kingsbury, W. J. No. 1,004.—Description of the Entrance, Entrance Lock, and Jetty Walls of the Victoria (London) Docks; with a detailed account of the Wrought-Iron Gates and Caisson, and remarks upon the form adopted in their construction. With a series of Diagrams.

Mallet, R. No. 992.—On the Coefficients, T_e and T_r, of Elasticity and of Rupture in Wrought Iron; in relation to the volume of the Metallic Mass, its Metallurgic Treatment, and the Axial Direction of its constituent crystals. With a series of Diagrams.

M'Master, B. No. 994.—On the Permanent Way of the Madras Railway.

Scott, M. No. 991.—Description of a Breakwater at the Port of Blyth; and of Improvements in Breakwaters, applicable to Harbours of Refuge. With a series of Diagrams.

Sim, R. No. 999.—On the Results of the Employment of Steam Tugs on Canals, and of other measures for the Improvement of Canals as a means of transport for heavy traffic.

Stileman, F. C. No. 1,009.—On the Construction and Enlargement of the Lindal Tunnel, on the Furness Railway. With a series of Diagrams.

Stoney, B. B. No. 997.—On the Construction of Floating Buoys and Beacons. With a series of Diagrams.

Swann, M. No. 998.—On Raising Submerged Vessels.

Tait, G. H. No. 1,007.—Description of a Swing Bridge at Port Adelaide, South Australia.

Wethered, The Honourable J. No. 1,010.—On Combined Steam.

[CATALOGUE

CATALOGUE OF PRESENTS.

BOOKS.

DONORS. TITLE OF WORK.

Adams, W. B. Road Progress; or, Amalgamation of Railways and Highways for Agricultural improvement, and Steam Farming, in Great Britain and the Colonies. Also Practical Economy in fixed plant and rolling stock for passenger and goods trains. By W. Bridges Adams. Tract. 8vo. Plates. London, 1850.

Airy, G. B. Results of the Astronomical Observations made at the Royal Observatory, Greenwich. 1857. 4to.

[Extracted from the Greenwich Observations, 1857.]

——— Results of the Magnetical and Meteorological Observations made at the Royal Observatory, Greenwich. 1857. 4to.

[Extracted from the Greenwich Observations, 1857.]

——— On the Mechanical Conditions of the Deposit of a Submarine Cable. By G. B. Airy. Tract. 8vo. Greenwich, 1858.

[From the Philosophical Magazine for July, 1858.]

Alexander, J. H. An Inquiry into the English System of Weights and Measures. By J. H. Alexander. Tract. 8vo. Oxford, 1857.

——— International Coinage for Great Britain and the United States. A Note by J. H. Alexander. Tract. 8vo. Oxford, 1857.

Allan, T. Allan's Systems of Inland and Submarine Telegraphy. Tract. 8vo. No place, or date.

Anonymous. Chambers and Champion's Patent Railway Breaks. Tract. Folios. Plate. London, no date.

——— The Handel Commemoration Festival at the Crystal Palace in 1859. Programme of Arrangements. Tract. 8vo. Plan. London, 1859.

——— London and North Western Railway. Time-tables for Enginemen and Guards. Southern Division and Branches. Tract. 8vo. London, 1857.

——— Cataloghi del Museo Campana. 4to. No place, or date.

——— Plans for a Submarine Communication between England and France. Tract. 8vo. Plates. Dublin, 1858.

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Anonymous. "Wet and Dry;" or, the Docks of London: being an Inquiry concerning the (proposed) Northfleet Docks. By Capel Court. Tract. 8vo. London, 1859.

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———— Illustrations to the Dictionary of Architecture. Parts I. and II. of Vol. for 1857-58. Folio. London., 1858.

Armstrong, R. High Speed Steam Navigation, and Steamship Perfection. By R. Armstrong. Tract. 8vo. London, 1859.

Art Union of London. Report of the Council for the year 1858, with List of Members. 8vo. London, 1858.

Bache, Prof., A. D. Report of the Superintendent of the Coast Survey, showing the progress of the Survey during the year 1856. 4to. Plates. Washington, 1856.

Bateman, J. F. Glasgow Corporation Waterworks. City Piping. Report on the re-arrangement and extension of the Water Pipes in the City. By J. F. Bateman. Tract. 8vo. Plates. Glasgow, 1858.

———— Report on the means of Deodorising the Sewage of Glasgow. By Thomas Anderson, M.D., and J. F. Bateman. Tract. 8vo. Glasgow, 1858.

Baranowski, J. Patent Automaton Railway Signals, for exhibiting the Danger Signal after the passage of each Train during a given time, (say for five minutes,) or until the Train has arrived at a given distance beyond, (say one mile). 4to. Plate. London, 1858.

Beardmore, S. The Globe Telegraph: an Essay on the use of the Earth for the transmission of Electric Signals. By S. Beardmore. Tract. 8vo. Cuts. London. No date.

Belly, F. Carte d'étude pour le tracé et le profil du Canal de Nicaragua, par M. Thomé de Gamond; précédée de documents publiés sur cette question. Par F. Belly. 4to. Plates. Paris, 1858.

Bidder, G. P. River Nene. Report of Robert Stephenson, Esq., M.P.; G. P. Bidder, Esq.; and George R. Stephenson, Esq., on the Improvement of the River Nene: with a Preparatory Letter from Mr. Robert Stephenson. 4to. Plate. London, 1858.

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Board of Admiralty. Report on the Teneriffe Astronomical Experiment of 1856. By C. Piazzi Smyth. 4to. Plates and photographs. London, 1858.

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———————— Tide Tables for the English and Irish Ports, for the year 1858; also the times and heights of High-water at Full and Change for the principal places on the Globe. Computed by J. Burdwood, R.N. 8vo. London, 1857.

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Bryson, J. M. Remarks upon the Drainage of London: shewing the amount of expenditure requisite to carry out Main Culverts, one on each side of the River Thames, in comparison with the amount needful to erect Works upon the Banks of the said River for Deodorising the Sewage, reserving the precipitate for use. By J. M. Bryson. Tract. 8vo. London, 1858.

Burn, C. On the Construction of Breakwaters, for Harbours similarly situated as the one at Dover. By C. Burn. Tract. 8vo. Plates. London, 1859.

Calver, E. K. On the Construction and Principle of a Wave Screen, designed for the Formation of Harbours of Refuge. By E. K. Calver, R.N. Tract. 8vo. Cuts. London, 1858.

Calvert, F. C. On the relative Power of Metals and Alloys to conduct Heat. Part I. By F. C. Calvert and R. Johnson. 4to. Plate. London, 1858.

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Cambridge Philosophical Society. Transactions. Vol. X. Part I. 4to. Cuts. Cambridge, 1858.

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Canadian Institute. The Canadian Journal of Industry, Science, and Art. New Series. Vol. III., Nos. 15-18; and Vol. IV., Nos. 19-21. 8vo. Cuts. Toronto, 1858-9.

Cator, G. A. The National Flax Company, Limited. Explanatory details, opinions of the London press, and commercial arguments in favour of the system proposed to be adopted, for the encouragement of the cultivation and preparation of Flax, under the plans and patented processes of G. A. Cator. Tract. 8vo. London, 1859.

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Chadwick, D. Borough of Salford. Report on the proposed establishment of a Police Superannuation Fund. By D. Chadwick. Tract. 8vo. Salford, 1858.

Chesbrough, E. S. Chicago Sewerage. Report of the results of Examinations made in relation to Sewerage in several European Cities, in the winter of 1856-57. By E. S. Chesbrough. Tract. 8vo. Plates. Chicago, 1858.

Colburn, Z., and Holley, A. L. The Permanent Way and Coal-Burning Locomotive Boilers of European Railways; with a comparison of the Working Economy of European and American Lines, and the principles upon which improvement must proceed. By Z. Colburn and A. L. Holley. Folio. Plates. New York, 1858.

Commissioners of Patents, through Bennet Woodcroft. Catalogue of the Library of the Great Seal Patent Office. Titles. 8vo. London, 1857.

——————— Ditto. Part II. Index. 8vo. London, 1858.

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Curley, T. Geological Observations on Coral Reefs, Volcanic Islands, and on South America; being the Geology of the Voyage of the 'Beagle,' under the command of Captain FitzRoy, R.N., during the years 1832 to 1836. By C. Darwin. 8vo. Maps and Plates. London, 1851.

Dempsey, C. D. The Practical Railway Engineer: a concise description of the engineering and mechanical operations and structures which are combined in the formation of Railways for Public Traffic. By C. Drysdale Dempsey. 4to. 4th edition. Plates. London, 1855.

Dobson, S. Report of Experiments made on board the 'Isabella Croll' (screw steamer), at Cardiff, in December, 1858, for the purpose of ascertaining the comparative economic value and usefulness, for Marine purposes, of the Steam Coals of Aberdare, in South Wales, and of Hartley, in Northumberland. By S. Dobson. Tract. 8vo. Plates. London, 1859.

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Earthwork, &c. By J. Dwyer. Tract. 8vo. Map. Dublin, 1852.

East India Company. The Annals of Indian Administration. Edited by M. Townsend. Parts II.—VII. 8vo. Serampore, 1857-8.

——————— The Indian Official Thesaurus, being introductory to Annals of Indian Administration. Compiled by M. Townsend. 8vo. Serampore, 1858.

——————— Budget of Public Works in the Madras Presidency for the Official Year 1858-59; submitted to the Government of India, with a Report on the new Projects of Magnitude included in it. Folio. Madras, 1858.

——————— Ditto for the official Year 1859-60. Folio. Madras, 1859.

——————— Memoirs of the Geological Survey of India. Vol. I. 8vo. Plates and Cuts. Calcutta, 1859.

——————— Reports on the Harbour of Beitkul in Sedashighur Bay. By Colonel A. T. Cotton, M.E., I.N., and Lieut. A. D. Taylor. Tract. Folio. Map. Madras, 1858.

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Fay, C. A Letter to Captain Galton, R.E., in reply to Lieutenant-Colonel Yolland's Report on Comparative Experiments with Messrs. Newall and Fay's Breaks. By C. Fay. Tract. 8vo. Manchester, 1858.

Gournerie, J. De La. Traité de Perspective Linéaire contenant les tracés pour les tableaux plans et courbés, les bas-reliefs et les décorations théatrales, avec une théorie des effets de perspective. Par Jules De La Gournerie. 4to. Folio Atlas of Plates. Paris, 1859.

Haywood, W. Report to the Hon. the Committee upon Improvements of the Commissioners of Sewers of the City of London, upon the application of Charcoal to the Ventilation of Sewers. By W. Haywood. Tract. 8vo. London, 1858.

Horeau, H. New Purifying Sewers for the Thames. By H. Horeau. Tract. 8vo. Cut. London, 1858.

Humber, W. A Practical Treatise on Cast and Wrought-Iron Bridges and Girders, as applied to Railway Structures and to Buildings generally. By W. Humber. 4to. Plates. London, 1857.

I. R. Istituto Lombardo di Scienze, Lettere ed Arti. Giornale. Nuova Serie. Tomo IX. 4to. Plates. Milano, 1856.

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Isaac, T. S. A History and Description of the Baltimore and Ohio Rail Road, with an Appendix. By a Citizen of Baltimore. 8vo. Map and Portraits. Baltimore, 1853.

———— Report on the Improvement of the Kanawha and incidentally, of the Ohio River, by means of Artificial Lakes. By C. Ellet, Jun. 8vo. Plates. Philadelphia, 1858.

Koninklijk Instituut van Ingenieurs. Uittreksels uit vreemde Tijdschriften voor de Leden van het. 1857-58, Part IV.; and 1858-59, Parts I.—IV. 4to. Plates and Cuts. 'sGravenhage, 1858-59.

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Latham, J. H. The Construction of Wrought-Iron Bridges: embracing the practical application of the principles of Mechanics to Wrought-Iron Girder Work. By J. H. Latham. 8vo. Plates. Cambridge. 1858.

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Macintosh, J. Macintosh's System of 'National Defence;' or "New Strategies in Warfare;" also his Official Correspondence with the British Government, disclosing "The True Cause" of the Continuation of the late War, from the clashing of the Naval and Military Departments; its Method; its Causes; and consequent Expenses. Tract. 8vo. Plate. London, 1859.

Mackie, S. J. The Geologist; a popular Monthly Magazine of Geology. Edited by S. J. Mackie. 8vo. Plates and Cuts. London, 1858.

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Mayer, E. Eclisses en-dessous pour les Chemins de Fer servant

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à consolider les joints des rails et à former des voies entièrement métalliques. Par S. Grandis. Tract. 8vo. Plates. Turin. 1859.

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Mitchell, J. On the Extraction of the Precious Metals, by means of Mitchell's Patented Amalgamating Machinery. Also, a Description of the various Modes at present in use for the treatment of Auriferous and Argentiferous Substances. By J. Mitchell. Tract. 8vo. Plates. London, 1858.

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[OFFICERS.

OFFICERS.—1859-60.

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January 10, 1860.

GEORGE PARKER BIDDER, President, in the Chair.

THE following Candidates were balloted for and duly elected :—ROBERT PEARSON BRERETON, as a Member; and JOHN TOPHAM, as an Associate.

Mr. BIDDER addressed the Meeting in the following terms, on taking the Chair, for the first time time, after his Election as President :—

GENTLEMEN,

I BEG to thank you for the distinguished position in which your suffrages have placed me. Looking back upon the eminent men who have successively occupied this chair, I cannot but feel anxious, that the high character of our profession, and the efficiency of this Institution, should not suffer any abatement, during the term of my tenure of office, and considering the powers, and high professional position, of my predecessors, this anxiety cannot but be increased; indeed, it is only in one respect that I can hope to place myself on an equality with those eminent men,—by zeal for your progress, and the ardent desire, I entertain, of conducting our discussions with impartiality and courtesy towards all who may address you. On this I must act, and I am sure you will give me your cordial co-operation and assistance.

Before entering on the main objects of my Address, I cannot but feel, that it would be unbecoming in me not to allude to the recent loss of two of our most eminent brethren, Mr. Brunel, and Mr. Robert Stephenson; although I am well aware I can add but little to what has been already written and spoken here and elsewhere, and in terms more eloquent than I can command.

With regard to Mr. Brunel, in common with you all, I ever admired the wonderful resources of his mind, his extreme ingenuity, his courage in facing difficulties of every description, and his great tact and resources in overcoming them, so long as he retained his physical power.

It has frequently been my lot to be placed in professional conflict with that gentleman, and I need hardly say that, in common

with every other member of the profession, I found him a very dangerous and most able adversary; but at the same time he was equally high-minded, and above all mean and pettifogging practices for accomplishing his objects. He was one of those men in whose minds private friendship was never interrupted by professional strife; and there never was a time, when if I needed it, I should have hesitated to recur to him for advice, assistance, or sympathy; whilst in private life, I can, from personal knowledge, attest his sympathy for distress, and his unhesitating generosity in pecuniary sacrifices to abate it. In his professional career, it appears to me, that full justice has not been done to the memory of Mr. Brunel;—I allude more especially to his exertions in accelerating the progress of Oceanic Steam Navigation. The 'Great Western' was a brilliant example of the correctness of his conceptions on this point. It must be conceded, that he was the first, clearly and practically, to conceive the advantages to be derived from augmenting the size of steamers, with a view to increased speed and to the extension of their voyages. Looking back, therefore, to the period of the construction of the 'Great Western' steamer, she must be admitted to have been an absolutely successful experiment, mechanically and commercially, and the names of Brunel, as the Engineer, of Patterson, as the Shipwright, and of Maudslay and Field, as the Constructors of the engines, can never be omitted from the records of Oceanic Steam Navigation. The next step was the 'Great Britain;' and so far as regards the construction of the hull, the efficiency of that vessel, even to the present day, bears ample testimony to the skill of the design; whilst her having endured a whole winter's buffeting of the waves, in Dundrum Bay, testifies to the strength of her construction, and to the powers of resistance of which iron vessels are susceptible. It must not be forgotten, that it was to this vessel, that the screw propeller was first applied on the large scale; and it should be stated, that by Mr. Brunel's exertions in experimenting upon the 'Archimedes,' the introduction of that mode of propulsion was greatly accelerated. The only part of this experiment which was not satisfactory, was the performance of the engines; and this may be mainly attributed to the fact, that instead of confiding their construction to men whose lives had been directed to perfecting that particular branch of engineering, Mr. Brunel took upon himself the responsibility of designing the machines. It may not be unbecoming here to remark, that genius, however great, cannot alone supply the results which can only be attained by a life-long experience in practical details. It is deeply to be lamented, that the life of our friend was not spared, to consummate his conception of the 'Great Eastern' steamship. This great experiment has been already partially discussed in this Institution, and there

does not appear to be any reason why she should not be mechanically successful; but all who have had extended experience in our profession are aware, that in all experiments, there will arise certain phenomena, which no human foresight can anticipate. Now seeing that the 'Great Eastern' is six, or seven times the bulk of any existing vessel, and seeing that this, of necessity, involved the application of two sets of engines, two kinds of motive power,—the paddles and the screw propeller,—bearing also in mind, that she was intended to encounter head seas, at a speed never hitherto contemplated, and knowing also the enormous forces which ordinary vessels have to withstand, in heading the waves, however slowly, in heavy weather, it might reasonably be expected, that in many respects her first trial would be somewhat disappointing. I sincerely hope, and I am sure that I carry your sympathies with me, in trusting, that there still remain in this country, sufficient skill, enterprise, and co-operative action, to bring this great experiment to a real test, and thus to complete the most fitting memorial to the fame of our deceased friend.

In alluding to Mr. Robert Stephenson, I cannot but feel, that I am scarcely in a position to take an impartial review of his career and of his character. For upwards of a quarter of a century I have enjoyed his most intimate, and I may add, his most affectionate friendship. Even this term is, perhaps, hardly strong enough, for throughout the whole of this period, his conduct towards me was that of an elder and affectionate brother; he has encouraged me in all he thought right, and has not failed to criticise all he deemed wrong, and had the necessity arisen, he would have applied his whole fortune, to his last sixpence, for my benefit. I have said, that our friendship has endured for upwards of twenty-five years, but our acquaintance extends over a much longer period, as we were in the same class and on the same benches, at the University of Edinburgh. Probably no member of our profession, either past, or present, ever availed himself more earnestly of varied opportunities of acquiring professional accomplishment, than did Mr. Stephenson; his early youth, passed with his father at Killingworth Colliery, his early manhood at Edinburgh, his engagements in the mines of South America, aud on his return to England, his occupations in perfecting the Locomotive, and in managing the works at Newcastle, his connection with the early Railways, and added to all these, his pursuit of the studies of chemistry and geology, which continued throughout his life, and even to within a few days of his decease, constituted a substratum of scientific and practical knowledge which few have obtained, and fewer still have the ability properly to apply.

It was one of the distinguishing characteristics of his professional

career, that however bold he was in the conception of an idea, as for instance, the Britannia Tubular Bridge, yet no one, with whom I ever came into contact, watched with more anxiety the completion of these enterprises, than did Mr. Stephenson. His mind was ever occupied in anticipating how, and in what shape, failures might arise, and no doubt, it might appear to many, that the precautions he took were often superfluous. But the experienced Engineer knows well, that if he relies upon the chances turning up in his favour, without due precautions being taken, the enterprise is sure to be attended with some disasters; whilst the mere act of taking due precautions seems to have the effect of averting the consequences they are intended to guard against; in short, the Engineer is never justified in trusting to the favours of fortune, whilst he has the means of guarding against her caprices. Another distinguishing feature in our late friend's career was his treatment of all those who were associated with him in his undertakings. His habit, with those who enjoyed his confidence, was to leave with them the utmost amount of responsibility, which he could possibly lay upon them; and never to interfere, except in cases of emergency, or where his moral influence was required, to prevent undue interference from superior authorities. The consequence has been, that over the whole face of the globe, there are men of his school, who have risen to competency and to eminence, and who live to extol and respect the memory of their revered chief.

Of his successful professional career, his unbounded generosity, the liberality of his views, and the dignity and urbanity with which he filled this chair, you are all witnesses, and it will be long before the place is adequately filled, which his decease has rendered vacant.

In approaching the subjects which ought to be considered the main object of this Address, I would venture to remind you of the custom of our Society, which is, that although we publish all that is said, during the discussions and in the Addresses of our Presidents, yet it is always with the distinct understanding, that the remarks are not intended to represent the collective opinions of the Institution, but only of the individuals who utter them, and that they are not to be entitled to any more weight, than the intrinsic value of the opinions themselves, or that which the position of the speaker may secure for them. I am well aware, that even in my Address, I ought to make every statement without reference to personal convictions; but upon many subjects my opinions are so strong, that I cannot hope to escape developing the bias of my own mind. I trust, therefore, that this will be deemed excusable, bearing in mind the general understanding with regard to the transactions of this Institution.

It will be obvious to you all, how great are the obstacles to giving novelty to each successive Address of your Presidents, and how increasingly difficult it is, to render them interesting and instructive; it is not, therefore, my intention to advert to any of the topics which have been heretofore treated of, on any of those occasions.

The steps in the progress of our profession, measured chronologically, are very unequal, as indeed is the case with all sciences, abstract, or practical. When the mind of man is first released from thraldom and in the early stages of civilisation, it makes rapid and striking advances, until a certain stage has been attained. Indeed, the progress of the human mind, in every branch of knowledge, may be compared to the course of a stream, emanating from a spring in some distant mountain recess; emerging into light, it pursues its course amidst rocks, through woods and over cataracts, affording abundant scope for the poet and the painter, and subsiding at last into the slow, gentle, majestic stream, pursuing its way through the lowlands, in its approach to the ocean. Such is the course of science; and although its latter stages do not present the vivid contrasts which accompany its early course, yet they are not less important, nor less instructive; but the skill which is demanded, to point out their effect and character, is of a much higher order, than is required to indicate the early phenomena. From this task, gentlemen, I shrink, with an innate conviction of my inability to treat the subject as I should desire. The object, therefore, of my Address will be to allude to subjects which have not, hitherto, prominently occupied our attention, or afforded ground for our discussions, with the express intention of inviting your consideration of them, and the design of securing their discussion at our Meetings.

An objection may, perhaps, be raised, that I may be seeking to extend unduly the professional sphere of the Civil Engineer; but I have been long enough in the profession, to see it grow, from a mere craft, or mystery, into a scientific pursuit. This Institution, which may be regarded as representing the objects of the profession, now embraces among its Members, not only those who are engaged in the construction of roads, railways, harbours, &c., but those, also, who are occupied in the construction of engines and machinery, adaptable to every conceivable purpose, in the building of vessels, in the erection of gas and waterworks, in the laying down of electric telegraphs, and in the drainage of towns and rural districts. In short, if I was now called upon to define the object and scope of the profession of the Civil Engineer, I should say, that his particular province is to take up the results discovered by the abstract mathematician, the chemist, and the geologist, and

to apply them practically for the commercial advantage of the world at large; and to diffuse their beneficent influences among all classes of his fellow-creatures.

Among the objects which appear principally to demand our present consideration, are those questions most referable to Hydraulic Engineering. It is in this part of our professional study and practice, I am bound in candour to say, that the least satisfactory progress has been hitherto achieved, and upon these subjects, the discussions in our Society have been the most inconclusive. I believe that it is, in a great degree, owing to the fact of sound hydraulic knowledge being so little prevalent, that so many obstructions have arisen, to the progress of public works. It is impossible, otherwise, to suppose, that the errors, which have been committed in the Health of Towns Commission, would have occurred, or that a Blue Book, outraging all the discoveries of science, would have been published at the expense of Government, had our profession been sufficiently alive to the subject. It is, perhaps, hardly fair to visit some of our public departments with the severity of criticism which has been applied to them, by those to whom they may have been opposed, when it is considered how little unanimity of opinion prevails among ourselves, on some important points connected with this subject; and it must be borne in mind, that the gentlemen in our public departments have nothing to gain, in any way, by sanctioning a scheme, however successful, whilst on the other hand, should injurious consequences result, they might be exposed to grave responsibility.

The points of the utmost importance, upon which to arrive at a clear understanding, are the relative effects of the scour upon our rivers and harbours, arising from the action of tidal, or of land waters. I am free to admit, that I am one of those who attribute the smallest possible effect to the action of land waters, whilst I do attribute the most important effects to the action of tidal scour. This conviction has been forced upon me, by a general view of our rivers and estuaries. Looking, for instance, to the river flowing past our doors, the River Thames, can it be supposed, that the mere driblet of water falling over Teddington Lock, even in seasons of the highest floods, can give any effectual aid to the tidal currents, in preserving the channel from the sea to the Nore, and up to above Gravesend? Looking also to the fact, that when any great change, or improvement has taken place, in any of our rivers, we find them always to result from some new arrangement of the tidal currents, as, for instance, at Lynn, in the Clyde, and in many other cases; on the other hand, where has any marked result attended, either the increase, or the abstraction of the land waters? Upon the solution of this ques-

tion depends the reclamation of large tracts of land, now lying, not only waste and absolutely useless, but, in their present state, exercising a most pernicious influence upon the population of the adjoining districts.

The time has arrived, when the effects of under-draining, now every year more actively pursued, upon the condition of our rivers, should receive most serious consideration. I recently adverted here to some anomalous results arising from under-draining, and showed, that in certain soils and under certain circumstances, the effect of under-draining would be to pass less water to the rivers, than had previously flowed into them. If this view is correct, precautions should be taken to provide for the possible effects of an operation, which is, otherwise, so rapidly augmenting the fertility of our soil.

Another feature in the drainage of towns demands attention;—the prevailing fashion of subverting the cesspool system and of introducing outfall sewers. One great inducement, hitherto held out, has been the prospect entertained of employing the sewage for the fertilisation of the neighbouring land. Losing sight of the beneficent provisions of Nature, for avoiding pestilence, it was assumed, that the sewage of towns would, necessarily, be of a highly fertilising character, and it is mainly due to the exertions of our Member, Mr. Hawksley, that this delusion has been, to a great extent, dispelled. Recent investigations have shown, that in towns amply supplied with water, the sewage contains very little, if any, fertilising quality; certainly, none of commercial value. Indeed, a careful consideration of the economy of our rivers might have anticipated the conclusion. Look at the course of the Thames flowing through this great city,—consider the enormous population on its banks, before it reaches the Metropolis,—what would have been its condition, had not running waters possessed that quality of self-purification, which renders the sewage of towns of no practical value? I trust, then, that this Session will not close, without our having well considered the conditions under which a well-regulated cesspool system can be properly applied; and under what circumstances towns can be advantageously drained by outfall sewers. Permit me here to express an individual opinion of what appears to me, to be a useful application of the income arising from the bequest of the late Mr. Robert Stephenson. In due course the decision of the Council, upon its application, will be announced; but in my individual opinion, instead of being divided into a number of small premiums, a considerable portion of it should be devoted, in one premium, at fixed periods, to rewarding Papers upon subjects recommended by the Council, and which require the devotion of considerable time and labour; and it should

be understood, that although the premium would be given for the best Paper, it should be only awarded, when the Paper possessed the required amount of merit to entitle it to that distinction.

I would beg here to announce my intention of devoting, during this current session, the sum of Forty Pounds, under the above conditions, for the best Paper upon the subject of "the Régime of Rivers;" and I would suggest, as examples, to those who desire to devote their attention to this subject, the changes now taking place in the River Thames,—the condition of the Waveney and the Yare, at Yarmouth,—the harbour of Wells, as an example of the tidal scour alone sufficing to preserve the navigation,—the Ouse, at Lynn, relative to which so many records exist, of the various operations executed there,—and the Tyne and the Clyde,—but, indeed, there is scarcely any river, which, if critically examined, will not afford the most interesting and valuable experience. I need scarcely point out to you, that the works of Du Buat, in extenso, and as abridged by Robison, with his elegant essay upon the history of rivers, combine the most ample, satisfactory, and interesting information on these questions.

There is another branch of the profession, which is now becoming most important:—the extension of the Submarine Telegraph cables, by which our most remote possessions are being brought into almost immediate contact with the Home Government. The experience, up to the present time has, however, been very unsatisfactory, whether we consider the condition of the cables laid across the Atlantic, or of several of those submerged in the Mediterranean, and as regards their duration after being laid down. It was the opinion of the late Mr. Robert Stephenson, whilst presiding over the affairs of the Electric and International Telegraph Company, that a cable could not be anticipated to last more than ten years, and he, therefore, insisted on an annual provision being made for this decay. On the other hand, there are other Companies possessing submarine cables, who will not make any such provision. This anomalous state should not prevail in a commercial community, such as ours. I have much pleasure in stating, that on this subject the Government have taken a very judicious and liberal course, in which I am convinced the opinion of the country will support them. A Commission has been appointed to investigate this question, with the most ample scope for their inquiries. Mr. Stephenson felt a great interest in this Commission, of which I have the honour also to be a member: since his decease the active duties have devolved upon our Associate Member, Captain Douglas Galton, of the Railway Department of the Board of Trade, and it gives me much pleasure to state, that from the indefatigable zeal which he devotes to this inquiry, information of the highest importance will become the common property of the country. The

inquiry has for its object, not only the best form of cable to be laid at great depths in the ocean, but also the electrical condition when laid. It is, no doubt, owing to the want of such a preliminary inquiry, that so large an amount of national capital has been wasted in such operations, and especially in laying that across the Atlantic;—this subject will, I trust, receive your attention.

There are many questions, which, it appears to me, we may discuss with advantage, in connection with our National Defences. It may be contended, that this subject scarcely comes within the strict limits of our professional pursuits; but seeing how important a part must devolve upon steam vessels, upon our harbours generally, and especially those of refuge, upon the railway access to the coast, and upon our artillery, the preparation of which has now been admitted to have become part of the duties of our profession,—inasmuch as the recent great improvements have been accomplished by Sir W. Armstrong, Mr. Whitworth, and Mr. Anderson, all civilians and members of our profession,—I do not hesitate to advert to this subject, to which the public attention is so much attracted, especially as I do not know any other arena where such subjects can be so advantageously discussed as in this Institution. There is no assemblage which commands more general intelligence, and certainly, none which contains so much mechanical knowledge. Applying our minds to this question, the first consideration is, what are the peculiar resources which England possesses, and what is most essential to be attained? As to our resources, they consist chiefly in our enormous and accumulating wealth, our boundless mechanical skill, and the genius to apply them. The object to be attained is the maritime supremacy of the narrow seas. We cannot, indeed, like the Continental nations, maintain large bodies of regular troops, nor have we, like our neighbours, a large reserve of seamen at command for emergencies. Before, however, applying these general considerations, I must advert to the fact of the small amount of novelty and of improvement in naval architecture, which have originated in our own Government Dockyards, especially having regard to the enormous total expenditure recorded. It is the fashion to visit the shortcomings upon the statesmen in power; but in point of fact, they are as little in fault as we are, who are sitting in this room. In a constitutional government, carried on through the agency of the House of Commons, the Government has not the power of selecting the best mode of carrying on the public departments, but is compelled to adopt that which, under the circumstances, is exposed to the fewest disadvantages; having reference to the uncertain tenure of office, it is, therefore, unreasonable and useless to complain of statesmen; the more patriotic course is to suggest practical remedies. The main

reason of so little improvement emanating from the public departments, is the total want of that competition which exercises so irresistible an influence on all our commercial relations.

I cannot help thinking that discussions, at our Meetings, on many of the subjects within the scope of the public departments, will be reflected upon these departments, and will work for the general good. I repeat, why should not the skill, talent, and practical knowledge which has so rapidly improved our artillery, and has been resorted to by Foreign Governments for their navies, be rendered available for our national objects? The Governments of Spain, Portugal, Sardinia, Austria, Turkey, and the Brazils, resort to our commercial shipwrights to form their navies, whilst Russia has recourse to the United States; the British Government alone despising the resources offered by the native genius of the country.

As to our national defences, the all-important point is, as before stated, the maritime supremacy of the narrow seas. It appears that, for this object, three conditions are essential:—

1st. That we should possess the fleetest boats, for conveying intelligence, instructions, and information as to hostile movements;

2nd. The strongest, swiftest, and most powerful rams, or vessels for running down;

3rd. Armed ships of the most efficient description.

As to the fast despatch-boats, they are to be had, in abundance, from our commercial and mail services; especially such as those now constructing for the Holyhead and Kingstown line.

As regards the rams, there are many points demanding serious investigation. The first is, whether they should be constructed simply to act as rams, or be provided with an armament, and combine the two conditions; and thus, whether in attempting to combine both objects in one vessel, the actual efficiency of both may not be impaired. That is to say, whether giving to the ram its adequate strength, may not interfere with its proper armament, and whether the provisions required for the armament may not defeat its object as a ram. It would appear to be obvious, that if a vessel were built solely for running down, and her sphere of action were restricted to the Channel, her form and the system of construction would not be essentially different from that which would be adopted, if her operations were to be more extended. It must also be remembered, that the crew required to work her, solely as a ram, would be very small, as compared with the additional number of men required to work a powerful armament, and upon the perilous service to which they would be applied, we should risk but few lives, which cannot be replaced, in addition to the property which we can so easily re-establish; and thus a powerful Channel fleet could be kept afloat at a small current

charge. These are surely points of sufficient importance to demand careful discussion and development.

The points to be considered relative to the fighting ships are, whether they should not, like the rams, be specially constructed for service in the seas surrounding our coasts. Our men-of-war are now all constructed for carrying the British flag into distant seas, and for this purpose they are adequately masted and sparred, to economise fuel on their passages to their destination. In a general engagement, the spars and rigging not only require the special attention of a large part of the crew, but their destruction endangers the efficiency of the means of propulsion, and thus, on an emergency, not unfrequently leaves the vessel a helpless log at the mercy of the enemy.

Now if a special class of vessels was solely applied to the Channel service, there would not be any object in so fully equipping them, and in burdening them with such cumbersome top-hamper. Neither would such capacity be required for provisions, water, and fuel for long voyages. Under these circumstances, it is worth consideration, whether an entirely new class of vessels might not be constructed, with less draught of water, sharper lines, more power, greater speed, and heavier armament, all essential elements in future warfare, and thus secure, for the nation, a fleet of vessels strictly applicable to defensive purposes, which no other nation would have the means of opposing, and insure, in future, for this country, that which it has hitherto possessed, the maritime supremacy of the narrow seas. Besides these points, there is the question, in what way the mechanical skill of the country and the constructive genius of commercial shipwrights, shall be rendered available for the improvement of our national marine. It may be discussed, whether the best course would not be, after defining the objects of any particular class of vessel required by the Government, to solicit designs from the principal builders; and in furnishing such plans, the builders should not only state the cost at which they will build, but also the speed they will guarantee, combined with the capacity to carry the specified armament, in a manner to insure the efficiency of the vessel; the selections from these designs to devolve upon a commission of independent members. I again repeat, that these may not be the best measures to be actually adopted, but their discussion within these walls must be productive of good.

Another branch of the subject is, the most facile method of concentrating forces upon those points accessible to an enemy. It has been suggested, that a littoral line of railway should be constructed. This proposition could only have emanated from those who were unacquainted with the physical features of our coasts. Shakespeare's Cliff, Beachy Head, the iron-bound coasts to the

west of the Isle of Wight, are familiar to all. But, in point of fact, looking to the existing railways, the problem admits of an easier solution than has been generally supposed. The South-Eastern, the East Kent, the South Coast, the South-Western, with its branch to Dorchester and extension to Exeter, the Great Western, Bristol and Exeter and West Cornwall, the South Wales, and other railways, either directly approach every accessible spot on the coast, or admit of easy connection by branches. The only points remaining to be considered are, the defensive works at those places. It is admitted, that nothing can be more unsatisfactory, than the state of the fortifications around our coasts. Lord Grey has graphically described those at Plymouth; and a short railway journey, and a cruise down the Solent, past the fortifications at Hurst Point, will prove, that neither scientific investigations, nor modern experience, have, as yet, had any beneficial effect upon that department which charges itself with the control of such works.

As a natural sequence to the preceding subjects, we are led to the consideration of the proceedings which have taken place, with regard to what are termed our Harbours of Refuge,—as it must be obvious, that one main object of these works has reference to the operations of our naval forces,—and I believe I am justified in observing, from what transpired during a recent discussion at this Institution, that neither mechanically, nor financially, can they be considered to be in a satisfactory position. According to the present system of conducting such works, it is obvious, that the principle of construction employed at Dover and at Alderney, must necessarily restrict their adoption to a very limited extent. Whether we look to the time, or to the cost, the results are altogether inadequate to the sacrifices required. The protracted time is, to a great extent, owing to the system of voting the funds annually by driblets, the result of which is, that neither the Government, nor Parliament, fairly appreciate, at the commencement of a work, the full extent of the responsibility involved, either as to time, or cost. Can it be supposed, that Government, or Parliament, when adopting the recommendation of the Commission to construct a harbour of refuge at Dover, imagined, that the works would involve an actual cash outlay of five, or six millions, without interest, or of thirty, or forty millions, including interest, and that a hundred years, at least, would elapse, before the full efficiency of the works would be secured; or that after an expenditure of nearly half a million sterling, and the lapse of upwards of ten years, the constructive resources of Great Britain would be exhibited, to the foreigner landing at Dover, in the shape of an incomplete jetty, with two incommodious landing places? These and other results, of a similar character, may be fairly attributed to the system

adopted, and must not be laid to the charge of any individual, or department, and certainly not to the eminent statesmen who guide the helm of the nation for the time being; for in matters of this description they possess no interest, political, or otherwise, apart from that of the country at large. No doubt one of the inconveniences of the present system is that of having to apply to Parliament annually for grants, the amounts of which, and the chance of obtaining them, depend upon the financial state of the country, and the temper of the House of Commons, even although the period of the session may be selected, when the Government has the best command of the attendance in the House. No doubt that, having regard to these circumstances, the original plans of the works have often been conceived on a limited and narrow basis, adapted to the proposed expenditure, but totally inadequate to the objects supposed to be attained; the ultimate result, generally, being an extension of the design, an enlargement of the estimates, and a final completion of the works, in a form, or shape which defies investigation to affiliate. Thus money is wasted, time is sacrificed, and full efficiency is not attained.

The remedy for this defective state would appear to be, that antecedent to any application to Parliament, the Government should prepare full and detailed plans of the entire extent of the works intended to be executed, and obtain tenders from competent contractors for the execution, stating the time of completion and the terms and mode of payment. These plans should be deposited, at fixed periods, at the Private Bill Office, for the inspection of all who are interested. Thus, before the vote was taken, there would be ample time for full criticism on all points, and though additional labour might be thrown upon the public departments, in preparing the documents subjected to such investigation, the House of Commons and the members of the State, would have the means of coming to the debate, fully informed on all points connected with these national works.

In a financial point of view the gain would be considerable, because a work which is executed within a reasonable time, is always more economical than one which is extended over an indefinite period; and also for direct financial considerations; which may thus be exemplified. Suppose a work, estimated to cost a million, be made to extend over twenty years, the outlay being restricted by the annual grant, to fifty thousand pounds a year; the ultimate cost of this work to the country, assuming the Government to raise the money at three per cent., involves an additional annual charge of about forty-two thousand pounds per annum; whereas, if the work was executed in five years, by annual grants of two hundred thousand pounds a year, the annual charge to the country would only be thirty-three thousand pounds a year; thus,

irrespective of all other advantages, saving nine thousand pounds a year. These observations only apply to works of real utility, and do not apply to undertakings of so useless a character, that their execution cannot be too long protracted; such, for instance, as the pier at St. Catherine's, in Jersey, and others of a similar character.

I cannot but feel assured that, were the principle adopted, which I have enunciated, the defects now admitted to exist in the harbours of Holyhead and of Alderney would have been avoided, and the Blue Book mystification at Portland, respecting the expenditure upon the convicts employed on the breakwater works, would not have occurred, and the nation and Parliament would have had the satisfaction of realising, in all these works, the full value of the outlay incurred. Ministers, by taking at once from Parliament a grant for the full amount of the expenditure, would avoid the annoyance of the annual appeal and the recurring waste of the public time, in re-discussing all the features of these undertakings.

I have alluded here to certain defects which will always be inherent in the harbours of Holyhead and Alderney, both of which were, doubtless, originally projected on so limited a scale, on account of the difficulty of obtaining Parliamentary grants; but during the progress of the works, their total inadequacy for the objects proposed became so obvious, that it would have been absolutely criminal to have persisted in the original designs. Their extension, therefore, became a matter of necessity; but, alas! these extensions could only be carried out in such directions, that it is now admitted, that for the same amount of money, the same extent of breakwater might have been constructed, in a form much better calculated to resist the action of the seas, whilst affording more security and nearly twice the amount of accommodation.

Before concluding my Address, I cannot avoid contrasting the progress of Government works with those undertaken by private enterprise. There is, within a short distance, an iron bridge, scarcely even partly completed, across the River Thames. There is no doubt, that this bridge will be substantially and skilfully constructed, but it cannot be said to involve any feature of mechanical difficulty: it is constructed in London, and thus commands, in respect of labour and materials, the resources of the whole empire. Another iron bridge, spanning the River St. Lawrence in Canada, is entirely completed and is opened for traffic: this bridge extends for nearly a mile and a half across a stream, having a current varying from seven to ten miles an hour; it has to resist the pressure of ice accumulating, occasionally, to the depth of thirty feet, or forty feet; the severity of the climate is such as to restrict the actual period of working, to a few months in each year; the ironwork

and the great proportion of the skilled labour were derived from England; and a severe monetary crisis had also to be surmounted, which latter, however comparatively unimportant in Government operations, exercises a formidable influence on private enterprise. Yet this entire work has been executed contemporaneously with the one uncompleted half of Westminster Bridge; thus evidencing what the Civil Engineer can do, when impelled by the pressure of private enterprise, as contrasted with his exertions, when trammelled by the restrictions incidental to the conduct of Government works.

Gentlemen, I am well aware, that the observations I have made are open to the severest criticism. I have advisedly introduced into my Address, subjects and opinions of the most controversial character, because it is my design to induce upon them the fullest and freest discussion. I have endeavoured, on the one hand, and I hope with success, to avoid subjects of trivial interest; whilst on the other, I have attempted to direct my remarks to subjects of national, commercial, and professional importance.

I have now been a Member of this Institution for thirty-five years; during that period I have been a careful and anxious observer of its progress, and the result of my observations leads me to believe, that nothing has tended so much to the steady growth of this Society as the animated discussions, which so frequently occur within these walls. This point may, however, be also a subject of controversy; but, gentlemen, I have only one further remark to make,—upon which I can defy controversy,—that all I have said within these walls, and my conduct, while occupying this chair, has been and will be inspired by the determination, so far as my humble powers permit, to perpetuate the prosperity of this Institution, and to maintain the reputation of the noble profession of which I am proud to be a member.

Being duly moved and seconded, it was resolved:—"That the President be requested to permit his Address to be printed and circulated with the Minutes of Proceedings."

January 17, 1860.

GEORGE PARKER BIDDER, President, in the Chair.

The discussion upon the Paper, No. 1,005, "On Arterial Drainage and Outfalls," by Mr. R. B. Grantham, was continued throughout the evening, to the exclusion of any other subject.

RESTORATION OF CRACKED BELLS BY TIN SOLDERING.

After the Meeting, Mr. S. Alfred Varley exhibited a cracked bell, the metallic continuity of which had been restored, by simply soldering the crack with tin, so that the bell rang as perfectly as before it was injured. It was explained, that tin had the property, when heated above its melting point, to nearly a red heat, of rapidly dissolving copper. If, therefore, the cracked bell, after being soldered, was kept for a little time, at a dull red heat, or nearly so, the crack would be filled up with an alloy of tin and copper, of nearly the same kind of composition as the bell itself, and in absolute metallic union with it, becoming quite as brittle and as sonorous as the other portions of the bell.

January 24, 1860.

GEORGE PARKER BIDDER, President, in the Chair.

No. 1,009.—"On the Construction and Enlargement of the Lindal Tunnel, on the Furness Railway." By FRANCIS CROUGHTON STILEMAN, M. Inst. C.E.

The Author is desirous of laying before the Institution a short description of this work, believing it to be the only instance in which a tunnel, originally constructed for a single line, has been enlarged to receive a second line of railway; the traffic having been maintained during nearly the whole time the works were in progress. In the course of the Paper, reference will be made to the various modes proposed for executing the works, and an explanation will be given of the manner in which they were finally carried out, as well as of the difficulties encountered and overcome.

Allusion must be made, in the first place, to the circumstances under which the tunnel for a single line was constructed. In June,

1847, a contract was entered into with Messrs. Fell and Jopling, for the construction of a tunnel of sufficient width for two lines of way, at a schedule of prices. This contract was annulled, after the works had been in progress about five months, in consequence of the monetary crisis of that period. After a suspension of about twelve months, a fresh contract was entered into, for a single line, which was completed and opened in June, 1851. A great increase in the mineral traffic of the district, due principally to the facilities afforded by the completion of the railway, was the result. Subsequently, an Act of Parliament was obtained for the formation of "The Ulverston and Lancaster Railway," of which Messrs. McClean, (V.P. Inst. C.E.,) and Stileman, (M. Inst. C.E.,) were the Engineers. This line forms the connecting link in the chain of coast railways between Lancaster and Whitehaven. It then became doubtful, whether the single line would be sufficient to accommodate the traffic. In August, 1854, therefore, the Directors of the Furness Railway Company instructed their Engineers, Messrs. McClean and Stileman, to prepare the contract drawings, &c., for widening the railway, and enlarging, or open cutting the Lindal Tunnel. The question of open cutting the tunnel was entertained, in case that plan might be necessary, to insure the regular working of the traffic, during the progress of the works. The additional cost of open cutting, instead of simply enlarging the tunnel, was estimated at £12,000. The works having been advertised, several tenders were received, from well-known tunnel contractors, by which it appeared, that the expense of the former method would have been more than double that of the latter. Consequently, it was determined to enlarge the tunnel, and the tender of Mr. William Tredwell was accepted. The length of the tunnel to be enlarged was 563 lineal yards, of which 176 lineal yards were in solid rock, and 387 lineal yards in loose material, the latter being specified to be lined with sandstone-rubble masonry. During the execution, the length of the tunnel was reduced to 460 lineal yards, of which 123 lineal yards are in solid limestone rock, and 337 lineal yards in loose material, lined with masonry.

It will be seen by Plate 4, that the tunnel was to be increased in width equally on each side, the level of the rails remaining the same. It was proposed, that there should be two shafts, one on each side of the existing tunnel, so that the mining operations could be proceeded with, and the materials be removed, without interfering with the shell of the small tunnel. This, it was intended, should act as a protection to passing trains, until some lengths of the large tunnel had been completed. In consequence of these conditions, the section of the proposed tunnel is considerably in excess of what is usually allowed for two lines of railway. The time allowed for the execution of the contract was three years,

as it was thought desirable to limit the operations to one, or two faces, or points, so that the miners and other workmen might become experienced in the peculiarities of this particular work.

After the contract deed had been entered into, and all the preliminary arrangements had been made, Mr. William Tredwell suggested, that another single tunnel, parallel with the existing one, could be constructed with less risk to the traffic of the line, than the proposed enlargement. At the same time, he offered to undertake the necessary additional excavation, and to complete the works for the same sum. There were many reasons why this proposition could not be favourably entertained. In the first place, there was no precedent for a work of this description. Again, the great disadvantages in working a tunnel for a single line are well known; the difficulty of properly lifting and packing the permanent way, (the stifling atmosphere, after the passage of heavy trains, preventing the platelayers from working for any length of time together,) and the condensation of the steam upon the rails, practically increase the expense of working. The gradient in this case is 1 in 100. The material to be passed through was known to consist of limestone rock, pinnle, loose gravel, and clay with boulders. The foundations throughout were good; and the difficulty that had been experienced in the formation of the original tunnel, in contending with the water, could hardly be expected to arise in enlarging it.

Before commencing the operations, a code of special rules was arranged for working the traffic, and for watching and signalling the trains. The line was entirely given up to the contractor, between the hours of 9 P.M., and 5 A.M., or for eight consecutive hours. No work was allowed to be carried on at other times, without the permission of the Resident Engineer. Telegraphic communication was made between the stations at each end of the tunnel, and a signalman was placed within the tunnel. Semaphore signals were erected at each entrance, and were connected by an endless wire, inclosed in a continuous trough. The wire was fastened to wheels at various points, having a crank outside the trough. The signalman was thus enabled, by means of a portable lever, to lower, simultaneously, the semaphore signals at each end of the tunnel. As a caution to workmen and others who might be in the tunnel, the signalman, on being acquainted, by telegraph, of the approach of a train, sounded a large gong; and it was only after satisfying himself, that no impediment existed to the passage of the train, that he lowered the signal, thus sanctioning the advance of the trains.

The works for the enlargement of the tunnel were commenced, in June, 1855, at the old shaft No. 3, which was widened, instead of two new ones being sunk, as at first contemplated. The shaft was

divided down the centre, by a strong timber brattice, so that it could be worked as two separate shafts, according to the original proposition.

Top headings were driven for short distances, at the proper levels, above the existing tunnel. The material was found to consist of dry, hard clay and gravel; but it was observed, both in widening the shaft and in driving the headings, that the ground had become set and broken up, from previous mining operations, to a much greater extent than could have been anticipated. As it was probable, that such might be the case, more, or less, throughout, and as it would, when wet, render mining very treacherous, it was thought advisable to make the tunnel for the double line, of less dimensions than at first intended. The crown was kept sufficiently high to allow the mining operations, in getting out the roof, to proceed, without interfering with the original tunnel. Wrought-iron centering was employed, where necessary, and a shield to support the masonry of the small tunnel, whilst a length was being excavated above, which served also as a protection to the railway. The roof of the first length was executed, by placing the cills for the support of the bars, 3 feet above the crown of the small tunnel, on which and on the material forming the sides, they rested. A portion of the masonry of the tunnel between the cills was then removed, and the excavation for the side walls was proceeded with. Working by shafts was afterwards dispensed with, the alteration in the size of the tunnel not permitting the excavation for the side walls to be taken out, before the masonry of the smaller tunnel was removed.

In order to obtain another face, or point, to work at, it was necessary to break through the original tunnel. This operation was commenced by drilling through the soffit of the arch, to ascertain the nature of the material above. If satisfactory, a manhole was made, and the earth was removed, by means of a bar, until the excavation was sufficiently large to admit a miner; the hole was then timbered all round, leaving the top open. Another length of a few feet upwards was excavated and timbered in a similar way; this process being repeated until the level of the top heading was reached. From this upright shaft, the headings were driven, and the ordinary method of tunnelling was adopted. After a few lengths were completed, a regular system of timbering and of working was instituted; little distinction being made between apparently light, or heavy lengths. The bars used were chiefly of larch, varying in size from 15 inches to 18 inches and 22 inches in diameter. They were placed 12 inches to 15 inches and 18 inches apart, round the roof, and were supported at each end by props from the cills, which were of pitch pine, from 20 inches to 22 inches square. A saddle, or half-balk, was placed on the

top of the cills, and fastened to it with wrought-iron glands. The cills were supported from the ground by two upright props, passed through the haunches of the small arch, down to the formation level of the tunnel, by which means, only a small portion of the weight of the roof was thrown upon the small tunnel. After the excavation had been completed to the cill level, and the materials removed to the masonry of the old tunnel, the arch was taken down, the side walls removed, and the excavation at the sides proceeded with. A portion of the small tunnel, from 2 feet to 3 feet in length, was always left in front of the cill, to prevent any materials falling on the railway. The cill was further stayed by raking struts, brought down to the formation level. Small cills were placed about half-way down the side walls, to carry the props supporting the ends of the first cill; and these were again propped down upon the foundations, as the material was removed. In addition to the upper cill, a second, or back cill, was often used, to assist in carrying the crown bars. This was either propped from the bottom, in a similar manner to the one previously described, or from the smaller cills at the sides. A framing, called by miners a 'horse. head,' was also frequently used. It consisted of two balks, or bars, placed upright, with a cross piece, or cap, at the top, of sufficient length to take the drawing bars, usually about seven in number. This, when well packed up to the bars, greatly relieved the cills, if placed at the ends, or reduced the length, if placed in the centre. When the ground was more than ordinarily heavy, the lengths of excavation were reduced from 15 feet to 12 feet, to 9 feet, and even to 7 feet. In some instances, it was necessary, after the roof had been timbered, to put in additional bars, called lining bars, between those already placed. These were propped from the cill, or were carried by horse heads. When well packed with the other timbers, they formed a nearly solid timber roofing, 14 inches to 18 inches in thickness, for 12 feet, or 14 feet round, exclusive of the polling boards between the material excavated and the bars.

Four years had elapsed between the completion of the small tunnel and the commencement of the enlargement. This was considered sufficient time for all settlements and runs, from previous mining operations, to have become consolidated. But the displacement of the roof had been very great; and from the nature of the material, the water appeared to have been impounded in the settlements, forming small reservoirs. One of these displacements, or cavities, was met with near shaft No. 4, the two faces being then 95 feet apart. In one heading the materials, which were very wet, consisted of clay, gravel, and large stones; and the whole soon became converted into mud, oozing through the timbers, filling up the heading, and displacing the framing. This continued for some time, and but little progress could be made with the heading. After

a large quantity of mud had been removed, the run subsided, and the excavation became more consolidated. Whilst extending the heading, for another setting, a continuous dropping was heard in advance of the work, giving unmistakeable signs of the proximity of some cavity, from which, no doubt, the mud had been issuing. Special precautions were then taken. On widening out the boundary, a large hole was discovered, the top of which was 70 feet above the rails, and about 28 feet below the natural surface of the ground. The mouth of this hole was timbered, and, as far as possible, the entire place was filled up. Through this ground the work was carried on during the day as well as during the night; but little additional time was gained, or progress made. The old tunnel being so small, the engines which passed through with heavy loads, up a gradient of 1 in 100, so completely filled the tunnel and the headings with steam and sulphurous vapour, that it was impossible for the miners to remain at work. Near this point the greatest difficulty occurred. On the completion of the original tunnel, the shaft No. 4 had been filled up, but the knowledge of its existence, as well as that of the cavity, rendered it necessary to proceed with great caution. Short lengths only were removed, and a large quantity of timber in bars, double cills, horse heads, &c., was used. The excavation for the heading under the cavity improved, whilst that in the heading at the other face began to show broken ground. This was at a distance of about 38 feet from shaft No. 4. The material, though loose, was dry, a vein of fine, clear, washed gravel, about 4 feet, or 5 feet in width, extending from this heading towards the old shaft. On widening out this length, the vein of gravel was cut across its full extent. From the first, it showed symptoms of running; and notwithstanding all the precautions taken by the contractor's agent, and despite the great exertions made by the miners, the length fell in, causing a cessation of the traffic. The mineral and goods' trains were resumed within six days of the fall; but the Directors thought it prudent to limit the working of the line to the goods' traffic only. An arrangement was then made with the contractor, to give up the line to him for ten, instead of eight consecutive hours; he undertaking to complete the work, in less time than was stipulated in the contract. After the fall, it was surmised, that the whole of the ground between the two faces was in motion; and that the cavity and the shaft had united, and had thus caused the accident. A disturbance of the natural surface of the ground was observable; and the material with which the shaft had been filled up, had dropped about 50 feet. The works were soon reinstated, fresh lengths were put in, and the work was completed beyond the shaft and the cavity, without further accident. During the construction of these lengths, the rest of the material in the

shaft fell down to the broken length, thus affording a means of examining the ground from above. It was then discovered, that the cavity and the shaft had not united, as had been supposed, and that the vein of gravel continued past the shaft, towards the cavity. The only explanation which has been offered as to the cause of the accident is, that the bed, or vein, of gravel had run out to, and round the shaft, forming a large hole; thus setting free the loose material with which the shaft had been filled, and allowing the entire contents to drop, at once, 20 feet, or 30 feet, nearly over the heading.

After the tunnel had been completed, and the shaft No. 4, and the ground over the broken length, had been made good, it was decided to examine the cavity from the top, and to ascertain if it had extended. It will be remembered, that, as far as practicable, it had been filled from the work below. This was fortunate, for it was discovered, that it had gradually extended upwards. Before the boring was made, a subsidence on the natural surface of the ground was observed, immediately above the cavity. This was soon filled up and made good, since which time no further settlement has taken place. It has been suggested, that the cavity was not the result of previous mining operations, but that it was a natural reservoir, supplying distant springs, and that the vein of clear gravel, or sand had acted as a conduit.

The masonry, both for the side walls and for the arch, was of fitted limestone-rubble, 2 feet to 3 feet in thickness, set in Aberthaw lime-mortar. The stone was obtained from the adjoining cuttings. During the execution of the works, daily reports were made by the inspectors, of the progress, and returns were given of the number of men employed. It appears, that a length of tunnel of 15 feet was excavated, on the average, by eighteen working sets, or shifts of eight hours, representing one day's work of sixty miners and seventy-five labourers, but some lengths occupied as much as thirty-three working sets, or one day's work of one hundred and three miners and one hundred and twenty labourers. Of this number, eight sets were generally occupied in getting in the crown bars. The amount of excavation in each length was about 300 cubic yards.

The time occupied in building the side walls of a length of 15 feet averaged two sets, and in building and keying the arch, eight sets, employing in all, thirty-two masons and forty labourers, one day each. The time of the masons and labourers was scarcely found to vary; any additional time was easily accounted for, by the difficulty in setting the masonry amongst the extra timbering used in heavy lengths. Setting the ribs, or centres, was generally done by a leading miner and some labourers; it occupied about two sets, employing two miners and ten labourers one day.

The total cost of the tunnel, as it now stands, is as follows:—

	£.	s.	d.
In 1849, the contract price for the small tunnel, per lineal yard, was	6	0	0
In 1854, the additional cost, when enlarged, was	21	4	0
Total cost, per lineal yard, of the double tunnel in rock	27	4	0
In 1848, the contract price for the small tunnel, lined with sandstone-rubble masonry, per lineal yard, was	15	10	0
In 1854, the additional cost of widening, was	38	0	0
Total cost, per lineal yard, of the double tunnel, lined with fitted limestone-rubble masonry	53	10	0

Supposing that the original contract, entered into in 1847, had been completed, the tunnel would have cost:—

	£.	s.	d.
In rock, per lineal yard	21	0	6
In masonry	45	0	0

or £6. 3*s*. 6*d*. per lineal yard less when in rock, and £8. 10*s*. per lineal yard less when in masonry.

That part of the tunnel, 337 yards in length, executed in masonry, was completed in sixteen months. For the first eight months, four faces only were in progress, during which time 87 lineal yards were completed, being at the rate of 2½ lineal yards per week, or less than 2 feet per week at each face. During the remaining eight months, nine faces were proceeded with, and the rate of progress was about 7 lineal yards, or less than 2 feet 6 inches per week at each face. The actual time employed in completing each length of 15 feet, has been stated to be, on an average, thirty sets, or days. If calculated according to the total time that the works were in course of construction, double the actual working time was consumed; it would therefore, appear, that for work of this character, it is necessary to allow the same time for contingencies as for the actual execution. In this particular case, great difficulty was experienced in obtaining workmen, and in keeping them regularly at work. Most of the materials were obtained from the district, but not the workmen.

Mr. Ramsden, (M. Inst. C.E.,) the General Manager of the Furness Railway, has furnished the following particulars as to the number of trains that passed through the tunnel, from the commencement of the works in June, 1855, to their completion in November, 1856:—7,494 passenger trains carrying 112,050 pas-

sengers; and 2,107 goods' trains carrying 204,566 tons of minerals, &c.: in all, 9,601 trains, exclusive of light engines.

Not the slightest casualty occurred to either description of train, nor any accident, even of the most trivial character, to any servant of the Company. Unfortunately one miner lost his life at the fall of the length, and a second by the firing of a hole whilst charging. Two, or three miners were also injured, from causes incidental to all tunnelling operations.

The Paper is illustrated by a series of diagrams, from which Plate 4 has been compiled.

[Mr. STILEMAN

Mr. Stileman regretted he was unable to furnish the detailed cost of this work, with which he had hoped to be supplied by the contractor, for this was a case in which labour formed one of the chief items of cost. The original cost of the small tunnel, which, when lined, was 14 feet 6 inches in height and about 12 feet in width, was about £6 per lineal yard of rock work, and £15. 10*s.* per yard of masonry. The aggregate cost of the tunnel, when completed, was £27. 4*s.* per yard of rock work and £53. 10*s.* per yard of masonry. He added, that the contractors who tendered, generally preferred, or proposed to construct a supplemental tunnel, rather than be subjected to the interruptions that must, of necessity, be caused by the trains passing during the operations. The total number of trains given in the Paper, embraced the period from June, 1855, to November, 1856, and averaged about eighteen trains per day.

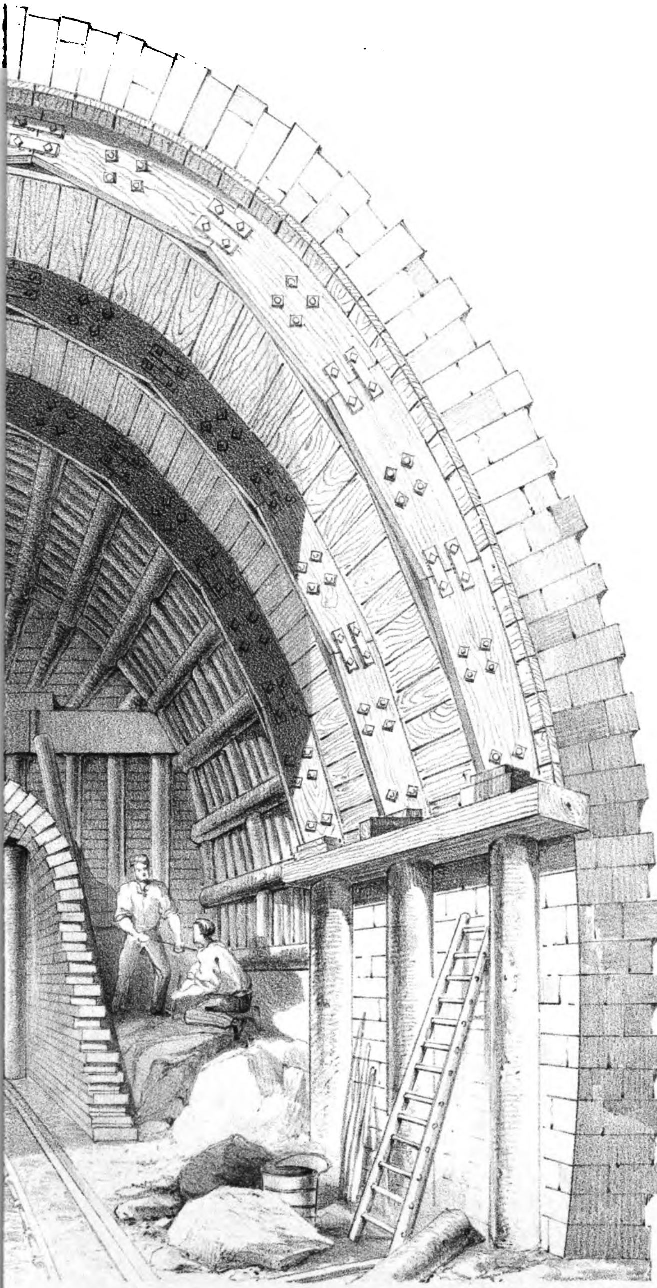
Mr. Hawkshaw, V.P., remarked, that the propriety of converting the tunnel of a single line of railway into one for a double line, in preference to the construction of a parallel tunnel, depended very much upon the amount of traffic. When there was little interruption from trains, the plan of widening the existing tunnel would, probably, be generally adopted. In constructing tunnels, he had found, that the larger the drift way was made in the first instance, the cheaper the work could be carried out. The former practice was to sink wide shafts and drive narrow drift ways, but in the many tunnels which he had constructed, he had been satisfied with shafts 6 feet in diameter; he had, however, used drift ways 9 feet square, from which the material could be carried away in the ordinary contractors' waggons. The widening of a tunnel, whilst it was in use for passing trains, was a difficult operation, requiring very accurate arrangement of the timber centering, and the utmost care in the execution. Upon considering the drawings of this work, he thought the design and the execution reflected the highest credit on those who had been connected with the tunnel.

Mr. Fowler, V.P., had constructed a supplemental tunnel, 3 miles in length, at the Woodhead Tunnel, on the Manchester, Sheffield and Lincolnshire Railway. He saw no reason why the same plan should not have been adopted on the Furness Railway, as no special precaution was required in the execution of the work, and the cost of the second tunnel was from two-thirds to three-fourths that of the first.

Mr. Knight was desirous of knowing how much the construction of the tunnel had cost the contractor, for at £6 per lineal yard, he must have been a considerable loser.

Mr. Hawkshaw, V.P., suggested that, in this case, the cost of making the approach to a second tunnel through the rock cutting, added to the cost of a second tunnel, would have been greater than

LWAY.



KEIL, BROS LITHRS CASTLE ST HOLBORN

that of enlarging the existing tunnel. No such general rule could be laid down, as that a second separate tunnel was always the best plan to be adopted.

Mr. Walker, (Past-President,) as one of the Directors of the Furness Railway, expressed his perfect satisfaction at the manner in which the entire works of the line had been executed; he also thought a single large tunnel preferable to two small tunnels.

Mr. Stileman, in reply to questions, stated that the old materials were not used in the construction of the enlarged tunnel. In considering the low price at which the original tunnel in rock was constructed, it should be remembered, that the tunnel was remarkably small, so that, on the average, the price was 6*s*. 2*d*. per cubic yard of solid rock. In this particular instance, the cost of a parallel tunnel would have been the same as for the enlargement; but the chief objection to the former of these methods, was the contracted space of the original tunnel, in which it was difficult for the platelayers to lift and pack the permanent way. The space was so confined, that although the tunnel was only 563 yards in length, it was impossible, during the construction of the works, to remain in some parts of it for any long period.

Mr. Bidder,—President,—regarded the Paper as one of great value in a practical point of view. It was true, that no absolute rule applicable to all cases, could be laid down, but there were instances in which the construction of a supplemental tunnel would be preferable to enlarging the first; and he concurred in the opinion, that it could be constructed for two-thirds, or three-fourths of the cost of the original tunnel. The cost of the original tunnel appeared, at first sight, extraordinarily small, but of this a sufficient explanation had been given, showing it to have been 6*s*. 2*d*. per cubic yard, which might be considered a fair price, when the material was not excessively hard. Tunnelling, generally, was one of the most interesting features of the profession, from the difficulties which had, in many cases, to be surmounted; the Kilsby and the Box Tunnels were remarkable examples of this, and would form subjects for interesting Papers. The details of those great works would be valuable and useful to the younger Members, and he hoped those who had information upon the subject at their command, would place it before the Institution.

January 31, 1860.

GEORGE PARKER BIDDER, President, in the Chair.

No. 1,015.—"On the means of Communication in the Empire of Brazil; chiefly in reference to the Works of the Mangaratiba Serra Road, and to those of the Mauá, the first Brazilian Railway."[1] By EDWARD BRAINERD WEBB, M. Inst. C.E.

WHEN Brazil was discovered by the Portuguese, in the year 1500, unlike Peru, or Mexico, it presented neither civilised inhabitants, nor visible wealth. It was entirely destitute of roads, or buildings, and its human inhabitants were as wild as the beasts of its boundless forests.

Notwithstanding its enormous area, equal to twenty-three times that of the United Kingdom, it offered, during the course of a century, but few temptations to the avaricious spirit governing the era of its discovery. Its coasts were, for a considerable period, used for convict settlements, and its only valuable export was the dyewood found in the neighbourhood of the sea. After the arrival of the Jesuits, however, a change took place. The first missionaries were heroic men,—at one and the same time, priests, politicians, and engineers,—and they effected what the sword had failed to accomplish, the civilisation of numerous hordes of savages. Teaching them the art of building, they erected villages and churches, cut and burnt down the forests, preparatory to agricultural operations, cleared paths between the various settlements, and, in later times, built towns and aqueducts. Although the attention of the traveller is frequently called to the former energy and ability of the Jesuits, he meets with no vestiges of ancient roads. He may, now and then, pass a time-worn church, or 'capella,' but he never crosses an antique bridge, for up to within a late period, no roads, in the English acceptance of the word, existed.

Brazil has a coast of about three thousand miles in extent. From time to time, at the entrances of the largest bays, and at the mouths of the principal rivers, settlements have been made, some of which have expanded into cities, whilst others have almost disappeared. With so great an extent of coast, and with a limited

[1] The discussion upon this Paper extended over portions of two evenings, but an abstract of the whole is given consecutively.

number of sites suitable for the construction of seaports, it follows, that they are frequently far distant from each other. Between these coast towns, the communication is by sea. People have penetrated into the interior at right angles to the sea shore, and having arrived at considerable distances inland, have formed junctions to the right, and to the left. Many of these internal lines of communication were, doubtless, first laid out by the 'anta,' or South American tapir, followed up by the Indians, and, ultimately, adopted and widened by the conquerors. The astonishment of an Englishman at the capricious direction of these routes, ought to be modified by the reflection, that they were equivalent to small tunnels driven through massive beds of vegetation; so impenetrable are the primeval Brazilian forests, from the lowest valley to the peak of the highest mountain. Up to within a recent period, these bridle paths were, however, sufficient for the necessities of the inhabitants. They were, occasionally, improved by avoiding a terrific ascent, by the erection of a wooden bridge, and even by the building of a stone culvert. These improvements, however, appeared only when some wealthy proprietor, for his own security, or convenience, executed them upon his own territories. The increase of the population and the development of commerce, led to increased traffic, and as the troops of loaded mules grew more numerous, the yielding paths became more unserviceable. The provincial governments then took the matter in hand, taxing the troops of mules, and repairing the paths by contract. These paths were treated as roads; but being unpaved, and for the most part, extending over a clay surface, with a width only sufficient for two mules to pass each other, they were and still are, at certain seasons, impassable.

The Province of Rio de Janeiro comprises two very distinct regions. A small portion, along the coast, is but little raised above the sea level; whilst the greater part is at an elevation above it, averaging about 2,300 feet. The sea face of this elevated land has, however, a much greater altitude. It is precipitous and rugged, presenting granitic peaks from 5,000 feet to 7,000 feet in height, and is called the 'Serra do Mar.' The roads from the interior to the seaports beneath, pass through the gorges of this Serra, and a few of these descents are now paved, at the cost of the province. The steepness of the gradients, from 1 in 6 to 1 in 9, permits the tropical rains to tear up all unpaved surfaces, trodden by the feet of mules. These animals, loaded generally with about 256 lbs. each, follow one another in single file. Rock gives way beneath such usage, and deep gullies are excavated, down which, during thunder storms, torrents rush with deafening noise. These paved descents of the Serra answered the end in view; but the difficulties inland and over the plains of the coast, continued.

The deterioration of the existing roads, by the increase of traffic, was marked by a continuous rise in the cost of slaves, mules, corn, and food. It then became apparent to all, that some efforts must be made to remedy the growing evil. At the head of the gorges leading towards the Bay of Rio de Janeiro, a small town, Petropolis, had risen into existence; first as a German colony fostered by the State, and afterwards, as the residence of the court and the wealthier classes during the hot season. The Government determined to make a carriage road up the face of the Serra leading to this town. It is not well laid out, nor are the works upon it considerable; it has only recently been macadamised. Its summit level is more than 2,800 feet above the sea, and it has an average gradient of 1 in 16. It was stated, without contradiction, in the Chamber of Deputies, that this road had cost the Government £40,000 per mile, although there were no disbursements for land, or for legal and parliamentary expenses. The first attempt at real road-making in Brazil has, therefore, been of a costly character.

The country between the head of the Bay of Rio and the foot of the Serra, is a sandy plain. The loss and suffering experienced during the passage of this plain, in hot and dry seasons, suggested the idea of a railway, and Senor Ireneô Evangelista De Souza, (now the Baron of Mauá,) obtained a concession for its construction. An Engineer arrived from England in 1851, and the works of the Mauá Railway were commenced during the following year.

Towards the close of 1852, the Author went to Brazil. He was immediately engaged in examining the country northward from the town of Petropolis, and in selecting a route for the continuation of the Mauá Railway; leaving, however, the Serra ascent intervening. This projected continuation of the Mauá Railway was subsequently abandoned, owing to the Government having decided in favour of a competing scheme, that of the Don Pedro Segundo Railway, the first section of which has recently been executed by Mr. E. Price, (Assoc. Inst. C.E.)

The first and most lasting difficulty met with by the Author, in determining the line of the proposed railway, was the absence of any correct map of the country. Maps there were in name, but they were worse than useless, because some reliance continued to be placed upon them, until their inaccuracy was proved. These maps are little better than itineraries depicted in lines; the distances upon them having been mainly determined, by the daily, or hourly progress of a saddle mule. A mule's march per day, is reckoned at about a Brazilian league, or four miles per hour; and the distance between two places is marked by leagues, regulated by hours. If the roads were rectilinear and horizontal, such a

calculation might approach to the truth; but as they bend in all directions, and at times, ascend gradients of 1 in 4, no true distance can be thus laid down on paper. On the same map, for example, an inch will represent, at one part, a league, and at an another, two leagues, or more; positions of towns will be found interchanged, and rivers running in impossible directions. The Author was, therefore, obliged to discard these maps. All they are serviceable for is to point out a tolerably true line of coast, and to give the names of interior towns, rivers, mountains, &c., in the various provinces.

Soon after his arrival, the Author proposed an arrangement, by which the Government should assist the Petropolis Railway Company, in a triangulation of the country on each side of the valleys through which the proposed line was to be carried. He ascended some of the most prominent peaks, and selected those best fitted for main stations. But the negociation failed; the Author, therefore, confined himself to the selection and the laying down of the railway route.

It is difficult to convey an idea of the labour of such an undertaking, conscientiously carried out, in a country like Brazil. Gangs of blacks were constantly employed in cutting paths, or headings, through the forests for the chain, theodolite, and level. It often happens, that to bring down one tree, six, or eight others must be felled, so closely do they grow together, and so firmly are their branches united, by ropes of wood. The surveying party lived in tents, and on no occasion desisted from work, on account of the tropical rains, or heat. The survey and levels for the selection of a length of main line extending to thirty miles, were executed in four months and a half. The Author then returned to the plains below, to complete the Mauá Railway, which was already commenced.

This line presented no difficulty, excepting where a deep, unhealthy swamp, from one mile to two miles in breadth, had to be crossed; there was no rock to be excavated, and no tunnel to be driven. But the prosecution of the works was difficult, chiefly on account of the want of available means. All the ordinary excavations were executed by lines of blacks jerking the earth behind them by means of hoes; if the weather was fine, the earth, consequently, arrived in the embankment, or spoil heap, in a state of dust. If the earth had to be taken to any distance, it was either carried in small baskets on the heads of slaves, often women, or it was jerked by the hoes upon a bullock's skin extended upon the ground, and drawn lazily by two sleepy oxen to the place of deposit. When rain had moistened the ground, a complete suspension of the operations took place. With the introduction of English barrows and shovels, and of small trucks and rails, a won-

derful improvement was made in the progress. Yet even then, the contrast between the result gained, and what would have been effected by English navvies, was very marked.

The poor native Brazilian is not inclined to work hard; necessity does not compel him to do more than to build a hut of sticks, plastered with mud, and roofed with palm leaves and tough grass. He plants a few banana trees, clears a small patch of ground for the mandioca root, or for the cultivation of black beans and rice, and all he cares for beyond, is to earn a trifle for clothes, rum, and tobacco. Slave labour, at the date to which the Author refers, could alone be depended upon, inasmuch as very little white labour was available.

The importation of slaves having entirely ceased, and all those already in the country being employed in the plantations, it was necessary, in order to obtain a supply, to offer high terms to the owners. The slaves were hired at monthly rates, and were housed and fed by the company. The wages of common blacks were about 1*s*. 4*d*., and the food cost about 7*d*., so that ordinary labour amounted to about 2*s*. per day. In 1857, however, after a lapse of four years, the price of labour and food had doubled. The cost of skilled labour was always about double that of the ordinary description.

With one exception, all the bridges were of wood; constructed with rapidity in order to expedite the opening of the line, and with the certainty of a not far distant renewal. Difficulty in obtaining sound and durable timber in Brazil would not, at first sight, be anticipated. Surrounded on all sides by grand, virgin forests, a stranger would imagine, that a large employment of timber in railway structures would be economical. Many circumstances combine to render this assumption incorrect. The Brazilian forests never present considerable areas covered with the same description of good timber, as in the pine forests; a serviceable tree generally stands in the midst of a group of various kinds of no actual value. The labour of dragging the squared balk from the place of its growth, is almost inconceivable. A separate path for each piece of timber has, probably, to be cut, and the log has afterwards to be dragged, by bullocks, down precipices, over ravines, and through swamps. Moreover, in consequence of the great inequality in the character of the timber, it is all but impossible to collect, in one district, a complete supply of one description. As a general rule, the timber is far from durable, when exposed to rain water, or sun.

Contrary to the Author's advice, a large and most expensive wooden pier was constructed for the southern terminus of the railway, in the Bay of Rio de Janeiro. The timber of this pier was selected from stores in the city; but it could not be obtained of

uniform quality, or of regular scantling, and when it came to the works, it varied from 9 inches to 18 inches square. The piles up to high-water mark were sheathed with copper, but before the expiration of three years, it was found necessary to fill up many of the bays with stone, as far as the worms and the sea water had damaged the piles.

Not long before the Author left Brazil, he made an examination of this pier, and he found, that not one pile, and but very few pieces of the superstructure, had remained in a sound state, although they had been in place for only about four years and a half. The copper had been decomposed, and for all practical purposes, had proved useless. All the wooden bridges on the line suffered as much as the pier, and they have recently been replaced by constructions of either iron, or brick. In the wooden bridges not one pile, transom, or longitudinal, could be called sound, and a considerable portion had been reduced to powder. The planking of foreign pitch pine appeared to have escaped with the least injury. The Brazilian pine cannot be used on railways, for it is a very inferior timber, and is a scarce tree along the coast. It is true, that timber exists in the province of Rio de Janeiro, capable of enduring exposure for a great length of time, but it is becoming scarce, and is, for general railway purposes, unavailable.

The rails used were double-headed, weighing 65 lbs. per yard, and they have proved sufficiently heavy for the traffic. They were seated upon Greaves's sleepers, which have answered admirably, in conjunction with very clear quartz ballast. Had sleepers of native wood been employed, the whole line must have been relaid at the end of about three years and a half. The gauge is 5 feet 6 inches, and although it was the first railway structure in Brazil, it did not determine the national gauge. Other Brazilian lines are now being constructed, with a gauge of 5 feet 3 inches.

As to the shape of the rail, it may be remarked, that if the capability of turning the double-headed rail is an advantage in England, it becomes a matter of serious importance in a country so far removed as is Brazil, from the seat of the iron manufacture. Several instances occurred on the Mauá Railway, where rails early showing defects, were reversed in their seats, to manifest advantage; with any other form, those rails would have been thrown aside, and old, or unserviceable wrought-iron may be considered as valueless in Brazil. The double-headed rail may not present the strongest section with a given quantity of metal, and its advantages may be lessened in some localities, where excessive weights cause the chairs to produce indentations; but as neither heavy engines, enormous traffic, nor extreme speed, are likely, for many years, to become features in Brazilian railways, the double-headed rail is, probably, the most appropriate for that country. The rails

do not appear to have been oxidised more than is customary in similar positions in England, nor have the cast-iron sleepers deteriorated.

The district through which the line runs is very swampy, and it proved most unhealthy. All who were engaged in the works, sooner, or later, were struck down by marsh fever. The heat, at times, was excessive; the temperature of the ballast, pure quartz, larger than sand and smaller than ordinary gravel, rose to upwards of 140°. Yet sickness in such situations seems attributable, as much to the impurity of the water consumed by the labourers, as to the excessive heat, or to the vitiated air. A supply of pure water to workmen, in similar positions, would repay a large expenditure for its carriage.

As to the cost of the line, which was single, and of about eleven miles only in length, it is difficult, under the peculiar circumstances of the undertaking, to extract from the total sum expended, that which is absolutely due to the railway works. The company has purchased steamers, slaves, lands, and houses. The works, however, with the rolling stock, may have cost about £15,500 per mile. The traffic on the line shows a continuous increase, and the undertaking will, eventually, offer satisfactory remuneration. It was the first railway constructed in Brazil, and considerable unnecessary expense was, consequently, incurred. It has to compete with an old-established river route, which is still kept open by prejudice and pertinacity; and it failed in obtaining that which promised to be its great source of profit, the continuation northward above the Serra, from Petropolis.

The line has not, like other Brazilian railways, enjoyed a Government guarantee; it paid the penalty of innovations. But it has its satisfactory aspects; it has been in daily use for nearly five years, without the loss of a single life; it remains in excellent condition, and it is worked by an English Engineer, with the most laudable economy and efficiency.

Soon after the opening of the Mauá Railway, the Author was appointed Engineer to the Mangaratiba Serra Road, to which he will now direct attention.

Upwards of one hundred miles to the west of Rio, occurs one of those Serra gorges already referred to. It descends to the port of Mangaratiba, one of the principal spots whence coffee is shipped for the capital. From the summit of the Serra, tracks similar to those already described, branch in various directions; one northerly, towards the interior province of Minas, reaching the great River Parahiba at a distance of about fifty-five miles from the coast, was the route of the projected road.

The land traffic to and from the port of Mangaratiba had con-

siderably increased during late years, and the roads had become less practicable. About 22,000 tons of coffee annually descended to the port, and the cargo mules returned up the mountains with about 10,000 tons of general merchandise, consisting of English and French mauufactures, North American flour, and South American dried beef. The Serra ascent had been paved to a width of about 9 feet, at an average gradient of 1 in 9. This pavement sloped inwards to the hill sides, where an open paved drain carried the rain water into numerous dry stone culverts. Inland from the summit, at frequent intervals, the troops of mules had to encounter, in wet weather, pits of muddy clay where the bleached bones of many victims attested the dangers of the road. The difficulties as to the road and the cost of mules yearly augmenting, it was finally determined to construct a carriage road. A concession was granted, and a company was formed.

The contract with the Government, binding the company to certain conditions as to gradient, width of road, time of completion, and amount of capital, was made before any engineering observations had been commenced. It was believed by the promoters, that the first length of twenty miles, in which lies the Serra ascent, was almost ready for carriages; and when the Author pointed out the impossibility of transforming a gradient of 1 in 9 into 1 in 20, (the incline named in the contract,) throughout a rise of about 1,600 feet, he was but imperfectly believed, or scarcely understood.

The work was commenced in May, 1855, by a body of Chinese, a portion of a considerable number contracted with by speculators, in Singapore. They were, evidently, the scum of the population; utterly useless as labourers, they proved a continual source of annoyance and loss, and not one in ten was worth his food. The contracts were, eventually, handed over to the company, and the men were permitted to abscond. Mention is made of these people, because the Brazilian Government contemplated, at one time, the introduction of an almost unlimited supply of Chinese labourers. An Act was passed, empowering the Government to expend £680,000 in the importation of colonists, and they, at first, selected the Chinese.

From the same motives which have induced English labourers to seek homes and employment in the United States, the Portuguese working men have selected Brazil. So considerable was the number of emigrants, that the Portuguese Government deemed it necessary to obstruct the movement. Nevertheless, many thousands have entered the Province of Rio de Janiero during late years, and the works of the Mangaratiba Road were supplied with them. As the road was set out, small contractors appeared:

with scarcely an exception all were Portuguese, or inhabitants of the various islands belonging to the crown of Portugal. Each of these men brought with him from fifteen to sixty of his countrymen, and the gangs, thus formed, dotted the line of the works with their triangular huts roofed with grass.

The Portuguese labourers are a very hardy race of men, who can endure greater privation and exposure than English labourers. At first, they refused to use the barrow and the shovel; the hoe, their only tool, was not, however, so objectionable along the steep sides of the Mangaratiba mountains, as it was on the plains of Mauá; and in certain localities, from its acting as pick and shovel combined, it was even the best tool that could have been used.

For a great portion of its length, the road is cut out of the solid rock, except where the excessive steepness of the hill sides rendered breast walling necessary. Considerable lengths occurred of nearly, or quite perpendicular rock, chiefly of mica schist. Immense rounded masses of pure granite were met with on the Serra, and occasionally, on the plains below and along the interior. Trap dykes were frequent in the ravines, and dispersed throughout the cuttings, decaying masses of basalt and amygdaloid were to be found, but in no instance was a bed of gravel met with. On account of the general steepness of the hills, and of the heavy character of the rains, the alluvial soil is not deep: beneath the few inches of soil, there is, generally, a bed of red tenacious clay, merging into a substance full of feldspar. After passing through a portion of decayed rock, the solid gneiss, or mica schist, is reached. The solidity of the earth enables the cuttings to stand safely, in most cases, at a slope of ½ to 1. Were it not for this feature, the amount of walling on the Serra would have been immense. Much steeper slopes can be allowed in Brazil than in England, on account of the greater solidity of the material, and the absence of frost.

With the exception of the arched bridges and storehouses, none of the masonry contains lime. All the walling, the parapets, and the culverts are built dry. The abundance of stone and the great cost of lime, in its purchase and carriage, led to its rejection.

The slopes of the embankments stand firmly at 1 to 1. With a little care a rapid growth of a very thick-leaved grass can be produced, and this quickly protects the slope from the destructive action of heavy rains. Before the growth of this grass, however, great damage is frequently done in a few minutes by excessive rain, such as is never witnessed in England.

Simultaneously with the increase in the number of small contractors, the company purchased and hired slaves, so that, in a few months, more than two thousand men were employed. In

default of one single responsible contractor, the works were executed in detail; and at one time, there were no less than sixty-eight petty contractors at work. The control and direction of the groups created much unusual labour; for the work could not be handed over to them as in ordinary contracts, as few of them would have properly fulfilled an agreement. The Author, therefore, adopted the following system: a man on presenting himself for employment, stating that he could bring from fifteen to fifty men to the ground, received a length marked out by an Assistant Engineer, and having built his hut, he continued working until the completion of his length, without any engagement for price; well knowing, from previous examples on the works, that he would be paid according to the quality of his work.

In such a country as Brazil, little selection of workmen can be made. A number of men may be dismissed, or may leave, but they cannot, as in England, be readily replaced. The scarcity of labour places the workmen in a very commanding position.

A most serious consideration is the supply to the men of the necessaries of life. The Author had frequent cause to regret his inability to prevent the plunder carried on by the purveyors of food. It is not a mere matter of profit and loss with the contractors, or their men; the Companies and the Engineers are equally concerned in the cost of living. It is the basis of wages, and it regulates the content, or discontent of the men. It is, nevertheless, too often overlooked; either because its effects are not considered, or because it is held to be a subject beneath the notice of an Engineer. Yet on accepting the control of works in countries similarly situated to Brazil, he cannot reasonably look for that absence of harassing detail which he expects in England; he enters upon a foreign campaign, and unless he resolves to undertake, at one and the same time, the heavy responsibilities of a chief, and the minute labours of an assistant, he would act more honourably towards his employers, and with greater prudence in reference to himself, by remaining at home, where no such abnegation of ease, or the amenities of position, are required. It may be suggested, that such details belong to agents and not to Engineers; the Mangaratiba Road had its agents, but they are to be entered in the list of its difficulties and misfortunes.

The execution and quality of general work in Brazil is not satisfactory. The excavation of rock, for instance, is a tedious and uncertain process, chiefly carried on by blacks, who, in matters of teaching, are frequently not superior to intelligent mules. The masonry proved more satisfactory than almost any other branch of work. The Portuguese masons will make a good dry wall out of inferior materials, and with considerable celerity. The same cannot be said of their stone work in mortar; if left to them-

selves, the men spend as much time in filling the outer interstices, as in building the wall itself. On the Mangaratiba Road there was only one work worthy of note, in dressed masonry, and notable only on account of its cost. Although the Portuguese dress stone very fairly, their work, as compared with that of English stone cutters, proved in this instance, four times more costly. In a locality far removed from the shore, and, at first, difficult of access, a bridge with a chord of 52 feet, and a versed sine of 9 feet, occupied nineteen months of incessant labour. The coal, steel, iron, and lime, with the supplies of food, were carried to the spot, during many months, on the backs of mules. Timber has been shown to be unadvisable in Brazilian bridge-building, at all events, in Central and Southern Brazil; and the enormous cost of this cut-stone bridge, notwithstanding the most unwearied exertions to diminish expense, proves that stone is not economical. Without doubt, iron is the best material for bridges in similar situations. This bridge did not cost less than £24,000.

The Author, during his connection with the Mauá Railway, and incidentally, with the gasworks at Rio, witnessed the melancholy result of employing English workmen in such a country as Brazil. A certain amount of skilled English labour is, sometimes, indispensable; but the aim should be to reduce the necessity for it to a minimum. For example; five Englishmen were brought to the Mangaratiba Road, to superintend the formation of the macadamised surface: two of them, in a very short time died, one absconded, and two only remained. This will present about an average of the result of such speculations. The strongest constitution will, at times, give way under a complete change of climate, and too often the most temperate men indulge in intoxicating drinks and die of fever, dysentery, or delirium tremens. The existence of slavery is a great drawback, and even the general good treatment of the slaves adds, at times, to the discontent of English workmen.

The comparative scarcity of slaves augments the rate charged for their labour, and tells against the employment of free men; it is yearly becoming more difficult in Brazil to hire slaves for public works. On the Mangaratiba Road it was necessary, at one period, to pay about 3*s.* 6*d.* per day for common slaves, strong and weak, in a mass; and this price, added to the food, brought the cost of a slave's daily labour to 4*s.* 6*d.* Yet notwithstanding this high rate, the Author failed in inducing the greatest slave owner in the vicinity of the works, although he was in the possession of more than three thousand slaves, to let out a single black. If he could have spared only five hundred, he would have received for their hire, free of all expense, from £80 to £90 per day; but his constant reply was, that he had not sufficient hands to keep his own estates in order. The Mangaratiba Com-

pany advertised in the Rio newspapers, offering 3*s.* 7*d.* per day per slave, the company providing food, house-room, and medical attendance, but few owners sent their slaves.

If then, a public company was forced to offer such large wages for slaves, on account of the difficulty in obtaining free labour, what must be the position of those undertakings in Brazil where slave labour is not admitted? Yet when companies were formed in England to carry out two of the Brazilian lines of railway, the British Government insisted upon the exclusion of slave labour in the construction of the works. On one of these railways, a large importation of Italian labourers has been effected, at a continual risk of complete failure. On another line, it has been found necessary to offer most unusual inducements to the free natives to stay on the works, and yet it is almost impossible to keep up a regular force of from fifteen hundred to two thousand men.

The Mangaratiba Road was constructed with care, and has withstood the rains of several seasons. The macadamised surface is 23 feet wide. A flagged drain, 3 feet in width, runs on the mountain side, and on the outer side is a similar drain, 18 inches in width. A bed, 8 inches to 9 inches in thickness, is paved over the 23 feet, and on this pavement is placed a layer of granite metal, 7 inches in thickness. A dry stone parapet, 3 feet high and 2 feet 2 inches thick, runs throughout the whole length of the road. The works have cost about £12,000 per mile. The Serra portions presented great difficulties, and there is no road of the same length in England, with an equal amount of excavation and masonry.

The practical result of the Mangaratiba Road has proved, that animal power connot be used upon macadamised roads in the general traffic of Brazil, with the same advantage which many other countries have derived from it. Locomotive lines are too expensive for general use, and Brazil ought not, for several years to come, to attempt more than one locomotive line for each seaboard province, with the exception of Rio de Janeiro. These locomotive lines ought to run inwards, at right angles to the coast, for it is the interior that requires, and will most readily repay, the assistance of railways.

With the exception of the Amazon, on the north, and the Paraná on the south, Brazil possesses little internal water-communication: the rest of its rivers are obstructed by rocky rapids inland, and by impracticable bars at their mouths. Neither is it a country generally fitted for canal navigation; it must, therefore, always depend upon roads and railways.

Being convinced, by the experience referred to, that macadamised roads cannot be easily worked in Brazil, and that locomotive

lines are too expensive, except as trunk lines, the Author recommended the employment of tramways, and at the request of the President of the Province of Rio de Janeiro, he drew up a Report advising their use in a certain locality. In his Message last year to the Assembly, the President embodies that Report.

The railways now in progress, or in contemplation, are destined to work a commercial and social revolution in Brazil. They are all single lines. It is to be regretted, that in one instance, that of the Don Pedro Segundo Railway, the benefit which it ought to afford, will be diminished instead of increased, as the line is extended. After reaching a certain position inland, this railway loses its character as a trunk line, and branches to the right and to the left, in lines parallel with, and not far from, the coast; so that points will be reached, where it will be more economical to use common mule tracks for conveying produce to the seaports. On the other hand, had these two lengths formed one line extending into the vast expanse of the interior, the last mile would, in process of time, have become the most valuable.

Of a very different character is the proposed railway in the adjoining Province of San Paulo. Throughout its whole length, it runs in a rectangular direction from the coast. Another feature in its favour, is the means by which the ascent of the Serra is proposed to be effected. Whereas in the Don Pedro Segundo Railway, a route has been sketched out by North American Engineers, with a gradient, for many miles, of 1 in 55, for locomotive engines: on the San Paulo Railway, the Serra has been carefully examined, and a line selected for inclined planes.

There are now five railways in Brazil; the only one completed being the Mauá, a short line, and there are four others in progress. Two of these, the Don Pedro Segundo and the Canto Gallo Railways, run from the Bay of Rio de Janeiro; the third runs from Bahia, and the fourth from Pernambuco. There is one in abeyance, the San Paulo Railway.

Of these five railways, the San Paulo appears to open the most prosperous future. The Pernambuco Line lies nearly under the equator; it is not probable, therefore, that it will be assisted by a great increase of population through the instrumentality of immigration. But in the Province of San Paulo, the climate is similar to that of Spain. With a rich soil, bounded by the prosperous Provinces of Rio de Janeiro, Santa Catharina, and Rio Grande, and by the mineral Provinces of Goyaz and Matto Grosso, San Paulo offers great advantages to emigrants and colonists. It, most certainly, will be covered by an active and an abundant population.

Notwithstanding the stability and prosperity of Brazil, its public works and its agricultural operations are yearly becoming more and more embarrassed, on account of the scarcity of labour.

Hitherto, the supply of labour and the means of colonisation have been considered separately. In a Report upon a proposed road in the Province of San Paulo, and recently, in a document which the Author had the honour of placing in the hands of His Majesty the Emperor, the following system was advocated:—"That the Concessionaire of a public road should seek from the Brazilian Government, assistance in the importation of labourers with families; that the Government should liquidate the expenses incurred in the introduction of the females and younger children; that the enterprise should be charged with the expenses incurred for the male adults, and employ them at certain limits of wages in the formation of the road; that the most eligible sites should be fixed upon, on the borders of the road, for collections of cottages, and that these cottages should be prepared before the arrival of the people. The result would be, that the men, and their elder sons could, immediately after their landing, gain a livelihood. This would last during the construction of the road. In the meantime, the women and the children would cultivate sufficiently large parcels of ground, which ought to be allotted and given to the different families. Gradually, the temporary cottages would be replaced, by the emigrants themselves, by better structures, the children would become acclimatised, and ultimately, these collections of cottages would form the nuclei of future towns."

Public works might thus be made the instruments of populating the districts in which they are undertaken. The Author is informed, that this system, to a considerable extent, will be adopted on the San Paulo Railway. A sum of £10,000 will be set apart for the purchase of land to be given to the workmen.

In conclusion, the Author will refer to the important question of guarantees. Imprudently used, they may defeat the main object in view. Brazil has enjoyed a public credit unexcelled by any other nation, but by an injudicious treatment of the guarantee system, that credit, hitherto immaculate, may be stained.

Two very distinct methods of guarantee are in operation. The shares of the Don Pedro Segundo Railway appear only in the Brazilian market. Upon a stated capital, an interest of 7 per cent. is guaranteed, conjointly by the General and Provincial Governments. The shareholders of this railway have paid up only a small portion of the capital, and one-third of the whole has been raised by loan, in London, in the name of the General Government, at 4½ per cent. This amount has been handed over to the company. The difference between the 4½ and 7 per cent. is to form a sinking fund which will gradually replace the sum borrowed, and the capital of the company will thus, almost insensibly, be reduced by one-third.

The other method, that of guaranteeing foreign shareholders, as in the case of the two English companies managed by boards in London, does not, it must be confessed, owing to most unforeseen and unfortunate circumstances, offer much encouragement. It might have been expected, that with the guarantee of 7 per cent. from a Government whose public credit is so stable, the quotations of its funds on the English Stock Exchange, would not have varied so much as British Consols, and that investments in such undertakings would be eagerly sought after. The shares of each company are, however, at a discount. That company which appears to have caused this state of affairs, suffers the most severely: it has not only damaged a similar undertaking, but has prevented, for the present, perhaps the most legitimate of all Brazilian railway enterprises, from appearing before the British public. If no remedy can be found for the past embarrassments which have fallen upon one, or more of the Brazilian Railways, or no preventive for the future, it would be much more advantageous to the Brazilians to raise all railway money on loan, and avoid the threatened risk of one, or more of their main lines breaking down from financial disorder, when only half completed.

In England, the Empire of Brazil is scarcely better known than that of Japan. The dealers in securities only know, that her engagements are kept with unsurpassed faith; the merchant only knows, that she exports an immense quantity of coffee, and imports a large amount of English manufactures; but in reference to her past and present history, her resources, her people, her fertile lands, her constitution, and her probable future, all but utter ignorance prevails. The railway and other enterprises, now in the course of development, will dissipate much of the ignorance existing on this side of the Atlantic; and notwithstanding present railway misfortunes, it is to be hoped, that ultimately, Brazil, upon a calculation of the preponderance of good and evil, will not have to regret the epoch, when English capital, energy, and engineering skill, assisted her in utilising her own internal wealth.

[Mr. WEBB

Mr. Webb said, that since the Paper was written, the formation of the San Paulo Railway Company had become an accomplished fact, and the works upon the line were about to be commenced.

Captain W. S. Moorsom said, that the management of the works exhibited that administrative ability which every Engineer who entered a wild, or a new country must possess, in order to carry out, successfully, a project of that nature. He fully concurred in the observation, that Engineers must, in distant regions, conduct themselves with good temper, and must frequently combine with their own special duties, those of a superintendent, or clerk of the works. Much of the sickness of the labourers was, no doubt, attributable to the nature of the water in certain localities; but there was another circumstance which had a material effect upon the health of persons who worked in jungle countries. Under a tropical sun, where the soil was ferruginous, there was a greater tendency to fevers than elsewhere; those spots should, therefore, be avoided, as far as possible, in the selection even of a temporary habitation. With the single exception of the employment of slaves, and the high price of labour generally, in Brazil, almost all the statistical circumstances related in the Paper, seemed to apply to the tropics on the other side of the globe, where he had been principally engaged, especially in Ceylon. The soil was of the same character, and such facilities as did exist, were equally to be met with in both quarters. But he was astonished at the cost of £24,000, for a bridge which did not appear to have presented any great features of difficulty in construction; he supposed it must have arisen from experimental circumstances connected with it. It had been stated, that large erections had been made without the use of lime. That was a mode of building which he proposed to adopt for upright walls in Ceylon, where there were large quantities of stone, but where lime could only be procured at great expense. In tropical countries, the enormous masses of water, resulting from the sudden heavy rains, passed off with greater facility from dry stone erections, than from masonry built with lime.

Alluding to specimens of Brazilian vegetation upon the table, he remarked of one which resembled a twisted rope, that in Ceylon, it was used by the natives to swing themselves, in the manner of a pendulum, across rapid, or deep streams.

Mr. Bidder,—President,—referring to the statement in the Paper, that the cost of a bridge with a span of 52 feet, had been £24,000, and that a period of nineteen months was occupied in its construction, inquired how that cost had been ascertained, and the particular circumstances which had occasioned the expenditure of so large a sum. A similar bridge could be constructed in this country, for about £1,500, or one-sixteenth of the price; and there

was no apparent reason why the cost of the cuttings and other works should not have been in the same proportion.

Mr. BRUNLEES observed, that the contents of such a bridge might be estimated at 1,000 cubic yards; it must have cost, therefore, as much as £24 per cubic yard.

Mr. WEBB replied, that the amount was taken from the books, such as they were, kept by the agents of the company. The chief expense was for labour and food. Owing to bad agency, large numbers of the stone cutters frequently remained nearly, and at times, wholly, idle, even for several days together, for want of tools and food, but their wages continued to be claimed and paid. The cuttings and other works had not been attended with the same difficulties.

Mr. Webb, in reply to a question from Mr. Errington, said, that he had purposely avoided discussing, at any length, the question whether the double-headed rail was generally serviceable; he had simply pointed out the advantage to be derived from it in such a country as Brazil. Some rails on the Mauá Railway, for example, having, after a short time, shown defects on one surface, instead of being thrown aside, were turned, and had remained in use to this day.

Mr. EVAN HOPKINS had had considerable experience as to the cost of labour, in carrying on large works in the interior of South America, near the equator. He was much surprised at the cost of the bridge, as he had never paid more than four dollars per cubic yard, for what might be termed ordinary bridges, across ravines, and for culverts, embankment walls, &c., connected with the watercourses and roads for the mines. With regard to the quality of the timber in the lower region of the tropics, it was the same as at Panama, very inferior, and almost useless for permanent works. Although there were large forests of timber, there was, comparatively, little wood near the level of the sea, serviceable for building. Hence, before undertaking great works in that region, it was important to know, that the quality of the timber within the tropics, greatly depended upon the elevation. Timber growing at more than 5,000 feet above the level of the sea, was superior for building purposes to the timber growing below that elevation; hence the cause of the difference of cost in different localities. As he had stated on a former occasion,[1] all the timber required for the Panama Railway bridges, &c., had to be brought from the United States. At the Marmato gold mines, the timber was brought from an elevation of about 6,000 feet above the level of the sea, and was found to be of very good quality. At Santa Anna, which was within 4° of the equator, and only about 3,000 feet

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. ix., pp. 77-88.

above the level of the sea, he employed, and still continued to employ, wrought iron and cast iron for machinery, the wood of the country being unsuitable for that purpose. He had recently introduced the use of sulphate of copper, as a preservative for the framing and the mining timber. Upon his first arrival in South America, in 1834, to take charge of the Marmato establishment, he ordered a quantity of wood for machinery, houses, &c., and he was much struck with the remarks of the natives who had to supply the timber. They said they could not commence cutting it until the decline of the moon, because it had been proved, from time immemorial, that wood cut during the increase of the moon, was attacked by dry rot, and certain varieties would decay in less than three months. Europeans, on their arrival in the tropics, were apt to laugh at such a notion, and he confessed that, at first, he did not believe it, but he soon found, by numerous trials, that such was the fact; that timber cut in the tropics during the increase of the moon, was subject to rapid decay, or decomposition, whereas timber cut during the decline of the moon remained, for years, comparatively good. In the former period it was always full of sap; in the latter, much drier and more compact. Reverting to the subject of the Santa Anna mines, he stated, that iron was principally used for the machinery; but even in that locality, he obtained some timber for the framing which he had put up in 1839, and which had only broken down in November, 1859. Still, there was great difficulty in obtaining suitable timber in those climates at low elevations, and there was great expense attending the conveyance of timber from high elevations. At Marmato, he had paid as much as five hundred dollars, or six hundred dollars for pieces of timber for the axles of the stamping mills, in consequence of the expense incurred in bringing it from an elevation of 6,000 feet, down the mountains and across the ravines, to a spot, 4,000 feet above the level of the sea. He could fully confirm the statement, that the cost of labour was very considerably enhanced since 1847; all these questions should, therefore, be duly considered, before making estimates and undertaking any extensive works in South America.

Mr. Errington said, the Paper referred to the use of the double-headed rail, in a manner that had led him to ask for further information upon the subject. One advantage of that description of rail was shown to consist in the ease with which it could be turned, and in a country where the cost of materials was so largely increased by the heavy charges for transit, it was, undoubtedly, the best form of rail to employ. He had known these rails to have been in use, on one side, for eight, or nine years; and when they were turned, to have lasted equally long. He had largely employed this description of rail on some of the northern lines, and he could

state from personal knowledge, that upon portions of the South Western Railway, there were rails still in use, which had been laid down twenty-one years ago, and when he last inspected them, they were in very good condition. This was, of course, an unusual period of duration for rails, but those to which he referred, were of excellent quality.

Mr. HAWKSHAW, V.P., remarked, that it was of little value to state the length of time during which rails had been in use, without giving the number of trains which ran over them. Under certain circumstances, rails could be worn out in twelve months; in other cases, the same rails would last twenty-one years, or even more. Of the effect of tropical climates upon timber, he had been enabled to judge, by a residence there of nearly three years. But it was worthy of remark, that timber, when exposed to extremes of temperature, either of great heat, or intense cold, ceased to be durable. Having had some experience in its use, both in hot and cold climates, he had arrived at the conclusion, that it was not desirable to employ that material in either. It was probable, that in India, well-designed iron roads would prove the most serviceable. He did not consider, that rails supported by iron sleepers, were so well calculated for great velocities, as when they were laid upon timber; but speeds of 50 miles, or 60 miles per hour, were not required in those countries, and for all moderate speeds an iron road would be efficient. He was aware that in tropical climates, there were certain descriptions of skilled labour which cost considerably more than in this country; at the same time, it should not be forgotten, that an extravagant sum might be anywhere expended in dressing stone to particular forms, and there could not be any necessity for it, in constructing the bridge to which allusion had been made. Referring to a photograph of a structure with an ornamental arch, he thought the design was such as would make the dressing of the stone very costly in Brazil.

Mr. BRUCE said, it appeared from the Paper, that when the Author first went to Brazil, he found the implements used by the labourers, very crude and imperfect, and he introduced a mode of doing the work which he considered to be more effective. Mr. Bruce was desirous of knowing, whether any economy had resulted from the substitution of barrows and planks, for baskets and skins; for he had found it, in some cases, inexpedient to interfere with the ordinary native methods of doing work. He confirmed the statement in the Paper, that the sickness amongst the workmen was not so much due to the effects of the climate, as to the badness of the water which they drank. In carrying out works in hot climates, it was essential to supply, at almost any cost, good water to the labourers.

Reference had been made to the failure of the guarantee

system, and surprise was manifested, that the guaranteed shares of the Brazilian lines, should be at a discount. It had been said by the press, that so small was the confidence reposed by the British public in English management, that a Government which could, with ease, raise money at 4½ per cent., failed to command it at par, although giving a guarantee of 7 per cent., when that condition was affixed to the undertaking. Now, the fact was this, that the guarantees, though given by the same Government, were altogether different. The Paper had shown the difficulties attending a survey through such a country as Brazil, its inaccessibility, and the unforeseen expenses which might be incurred, in spite of the most careful estimate. Was it, therefore, surprising, that a guarantee on a fixed sum, based upon an estimate made under circumstances where it might be greatly exceeded by the actual cost, so as to reduce the guarantee far below its original nominal value, should not command the same confidence as one not liable to such contingencies? To the difference between the nature of the respective guarantees, and not to any want of confidence in English management, was to be ascribed the different position of the two stocks in a market, where any element of uncertainty operated most injuriously.

Mr. Fowler, V.P., remarked, that in considering the cost of works of this description, isolated facts were not of much value, without a full statement of all the circumstances connected with them. The Author had recommended the introduction of tramways, alleging that in countries like Brazil, railways would, in many cases, be too expensive. This question could not be discussed, without details of the kind of tramway recommended, its gauge, and the nature of the permanent way.

Mr. Evan Hopkins said, that with regard to the use of baskets and barrows, a distinction must be made between temporary and permanent works. It was not till some time after his arrival in South America, that he was enabled to introduce barrows amongst the native labourers, as they were accustomed to carry everything, even very heavy loads, on their backs, and the first barrows that were made were thus carried by the negroes, until they found the advantage of wheeling them. Baskets and bags were, however, often used to great advantage for temporary works in broken ground, not in the interior of South America alone, but also on certain portions of the railway works now carried on in Spain and Portugal; but in permanent works, such as mining, quarrying, &c., there was a great difference in the cost, if they were executed in the native fashion. The native labourers employed in the large establishments of South America, knew now the value of the barrow; they often accepted contracts, and there was very little doubt, that they were capable of adopting the best system of

mechanical appliances, if they were duly instructed by attentive and efficient agents. At the gold mines of St. Juan del Rey, in the interior of Brazil, the engineering and mining works were as well executed, as in any part of Europe.

Mr. WEBB, in reply, explained, that the photograph to which allusion had been made, was that of a drinking fountain built to commemorate a public event. Part of the cut stone had cost about £200, the number of blocks not exceeding eight. With regard to the difference in money value, between the common labour of the country and such labour as was ultimately adopted, he scarcely knew how to arrive at a just calculation. The dilatory manner in which the ordinary works of the country were conducted, precluded any satisfactory account of the cost, as to cubic measure, being kept. The earth was removed in small baskets, holding less than a cubic foot each; the work was carried on without any regularity as to the number of workmen, the hours worked, or the wages paid; the operations were suspended during trivial showers; so that there was no direct means of contrasting the cost of the two systems of labour. It had, certainly, been far from his intention to reflect upon English Engineers generally, with reference to their works in foreign countries: he had a very different feeling, in proof of which he would point to the concluding paragraph of the Paper.

With respect to the bridge of cut stone, which had attracted so much attention, it must be evident, that in bringing this subject pointedly before the Institution, he could have had no other object than to lay before his Fellow Members such information as he possessed, with reference to features which were, unfortunately, too frequently concealed, namely, the failures in works intrusted to their charge, either as regarded cost, or execution. He believed, that many Members would be able to recollect instances, within their own experience, where their calculations had proved erroneous. The calculations and estimates for this bridge were made, at a time when the financial prospects of the company were in a satisfactory condition. Timber was discarded, for the reasons he had mentioned in the Paper. The choice lay, therefore, between stone and iron. Comparative calculations led to the belief, that iron and stone would each cost about the same in that locality; but there was this difference; if iron had been selected, it would have been brought from England at the risk of a sea passage, having afterwards to meet the difficulties inseparable from a transit over rough mountain paths; whereas the stone being on the spot, there was every expectation of completing the work within a given time, so far as the supply of material was concerned. That the bridge should have cost such an enormous sum was not anticipated, and was chiefly due

to the incapacity of agents, and to the imperfections of a commissariat system over which he had no control. The workmen were irregularly paid; and instances occurred of men working from ten months to twelve months without a settlement, during which time the company supplied food to the men, in addition to their pay. This food, sent from the city of Rio, one hundred and twenty miles distant, was often very bad, and at times, even putrid. The evils attendant upon this truck system, aggravated by the sense of wrong due to irregular and long-postponed payments, very often occasioned strikes amongst the workmen, and the works were either suspended, or the men worked sulkily. This, of course, considerably increased the expense, and protracted the period of completion. Then the river, over which the bridge was built, was subject to sudden and enormous tropical floods, during which the works were unavoidably retarded. Finally, the complete isolation of the locality tended to augment every difficulty and to add to the outlay. After some time had elapsed, it became apparent, that the estimate would, from the causes enumerated, be insufficient; but the works themselves, and the general preparations, had advanced too far to justify a halt, or to make any great alterations: it was too late, in fact, to recede, and as the less of two evils, it was determined to follow out the original design.

He had brought this matter forward voluntarily; certainly not for self-gratulation, but as a warning, and in order to show, that the introduction into foreign countries of works, which in England, either as regarded construction, or simple ornamentation, would possess no interest, might, under certain conditions, cause serious embarrassment, even though placed, as was this bridge, on one of the great highways of the empire. He believed, that shareholders might, occasionally, apply similar remarks to some works which had been carried out, even in this country. In confirmation of some of his views, he might be allowed to quote a paragraph from a work by Mr. Hawkshaw,[1] in which it was said, that "it takes a long time for matters at such a distance, to be well understood in England." That remark was frequently applicable, even at the present day, to foreign works.

In conclusion, he would remark, that he who openly and frankly pointed out to others his failures, or errors of judgment, was the most likely person to avoid their repetition.

Mr. Bidder,—President,—said the object of the practical Engineer was not so much to produce works which should impress the mind, as to accomplish certain purposes in the most economical

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[1] *Vide* "Reminiscences of South America, from Two-and-a-half Years' Residence in Venezuela." By John Hawkshaw, F.G.S., M. Inst. C.E. London, 1838. Page 110.

manner. It was not surprising, therefore, that criticism should have been excited by the statement, that a stone bridge with a span of only 52 feet, had cost £24,000. The explanation, however, which had been given, reflected the highest credit upon the Author, and added to the obligation the Meeting was under to him, for bringing the Paper before the Institution.

He believed there was a general feeling, that slave labour could not be profitably employed upon works of this description. Although it might be cheaply obtained, it always proved to be less valuable, than free labour paid for at a much higher price; and the result of his own experience was, that in scarcely any country in the world, could the same amount of work be done at so small a cost, as in England. He concurred in the opinion, that in tropical climates, where wood was subject to rapid decay, it was very desirable, when practicable, to substitute iron; but he did not think, that iron could be used to equal advantage, in extremely cold regions. In many instances, iron sleepers were preferable to those of any other description. On the Egyptian Railway, Greaves's sleepers were used, and the Pacha of Egypt travelled, with his own special engine and carriage, upon that line, at a speed which was scarcely exceeded in England. With regard to the prosecution of railways under guarantee, it was an anomalous plan, and, in his opinion, an unsatisfactory one, for he thought it reflected, to some extent, upon the administrative qualifications of those who took charge of the works. His own conviction was, that if the guarantee, instead of being placed in the hands of directors, had been given to an experienced contractor, the stock of the company would have maintained a higher position.

February 7, 1860.

GEORGE PARKER BIDDER, President, in the Chair.

The following Candidates were balloted for, and duly elected: THOMAS MASTERMAN HARDY JOHNSTON, EDWARD PURSER, JAMES LAURIE RICKARDS, RICHARD JAMES WARD, FRANCIS WILLIAM ISHERWOOD WEST, AND EDWARD LEADER WILLIAMS, junior, as Members; EDWARD MIDDLETON BARRY, EDWIN BARTON, FREDERICK ROBERT BROWNING, ANDREW CUTHELL, THOMAS BARNABAS DAFT, ROCHFORT ASTLE SPERLING, and JAMES WILSON, as Associates.

No. 1,017.—"Description of the Works on the Netherton Tunnel Branch of the Birmingham Canal." By JAMES RALPH WALKER, M. Inst. C.E.

THE system of inland navigation was introduced into South Staffordshire at an early period. Without the facilities which it afforded for the conveyance of minerals and heavy goods, the mining and manufacturing industry of the district could not have been developed to its present extent. That its advantages have been appreciated may be inferred from the fact, that the Birmingham Canal Company now possesses 157 miles of canal, the ramifications of which reach nearly every colliery and ironwork in the district. Notwithstanding the construction of several railways, on which a large quantity of mineral produce is carried, the traffic on the canal continues to increase. In 1832, the total quantity of coal conveyed was 1,492,000 tons; and in 1854, it had increased to 3,100,000 tons.

The canal is on several levels, named after the chief towns situated on them. The Wolverhampton Level is 52½ miles in length, and 484 feet 3 inches above low water at Liverpool. The Birmingham Level is 34½ miles in length, and 19 feet 10½ inches below the Wolverhampton Level. The Walsall Level is 20 miles in length, and 45 feet below the Birmingham Level. There are also other levels, 50 miles in length. These levels are connected with each other, and with canals belonging to other companies, by upwards of two hundred locks. The most modern locks are 75 feet 8 inches long between the gates, and 7 feet 3 inches wide between the quoins. The largest boats which navigate the canal are 71 feet 3 inches, or, including the rudder, 74 feet 3 inches

in length, and 7 feet 1 inch in width. Their light draught is about 8 inches, and their loaded draught 3 feet 2½ inches. They carry about 33 tons; but, owing to the system of measurement in use, they pay toll only on about 26½ tons.

The natural features of the country offer considerable difficulties in the construction of canals. Through Rowley Regis, Dudley, and Sedgley, there extends a line of hills, portions of which rise to a height of more than 400 feet above the Wolverhampton Level. This range forms part of the watershed of England; the drainage on the south side being into the Stour, which falls into the Severn, and on the north side into the Tame, and thence into the Trent.

A passage through these hills, whether for a canal, or a railway, rendered the construction of a tunnel indispensable. Accommodation had long been afforded by the Old Dudley Tunnel, but its small size and the increase of the traffic, both conduced to render it insufficient. The object of the works described in this Paper, was to effect such a communication as would meet the urgent requirements of the district. In the year 1768, an Act of Parliament was obtained, for the construction of a canal, on the north side of the hills, from Birmingham to the Staffordshire and Worcestershire Canal at Autherley, near Wolverhampton. This was the first canal constructed in the locality. According to the system adopted at that period, and for some time afterwards, it followed nearly a contour line along the slopes of the hills. The length of the canal, therefore, was 22 miles, although the actual distance, in a straight line, is only 13 miles. In 1824, Mr. Telford was engaged to improve this canal. By cutting off the bends, the length was reduced to 14 miles, and by making a deep cutting at Smethwick, the necessity for three locks at that place, was obviated; the same level being carried from Birmingham to Tipton. A towing path was also formed on each side, and walls were substituted for the slopes, so that the whole width of the canal was made available. A sum of £500,000 was expended on these improvements, between Birmingham and Westbromwich.

Although not immediately connected with the works which form the subject of this Paper, it may be mentioned, that in 1841-43, a canal had been constructed from Toll End to Gravelly Hill, near Birmingham, from the designs, and under the superintendence of Mr. Walker, (Past-President Inst. C.E.) It is called the Tame Valley Canal, is about 8 miles in length, and has thirteen locks. Both from the magnitude of the works and the excellence of their execution, it is the most remarkable part of the Birmingham Canal.

In 1776, a canal had been constructed, by the Dudley Canal Company, on the south side of the Hills, from the Worcester Canal, at Selly Oak, to the Stourbridge Canal, at Brierly Hill.

This canal was on the Birmingham Level, and a communication was effected between it and with the Wolverhampton Level of the Birmingham Canal, at Dudley, by means of a tunnel, having three locks at the south end. In 1846, the Dudley and Birmingham Canal Companies were amalgamated.

The Dudley Tunnel is 3,200 yards in length. In the portions lined with brickwork, it is about 8 feet wide, and its height is 6 feet above the water level. There not being any towing path, the boats are propelled through it, by men lying on their backs and pushing with their feet against the sides and roof of the tunnel; this process is called 'legging.' It is performed by two men, hired for the purpose, who are paid at the rate of three shillings and sixpence for each boat. The time occupied in the operation is, usually, about three hours and a half. As, however, boats cannot pass one another in the tunnel, a certain number can only be admitted, alternately, at each end. Before the traffic was relieved by the construction of the works described in this Paper, the delay at the entrances was very great, as many as one hundred boats being frequently detained there for several hours, and in some cases, even for some days. In dry seasons, when the water in the canal fell below the usual level, boats had to be partially unloaded before entering the tunnel, and the cargoes were thus exposed to pilfering, which was carried on, to a great extent. The tunnel being placed on the summit, or Wolverhampton Level, while all the canals at the south end, and most of those at the north end, were on lower levels, many of the boats had to ascend and descend three locks; this would have been unnecessary had the tunnel been on the Birmingham Level. Notwithstanding these inconveniences, this tunnel continued, for many years, to be the only means of communication between the Birmingham and the Dudley Canals. In 1845, 25,916 boats; in 1853, 41,704 boats; and in 1854, 39,025 boats, carrying 438,000 tons, passed through it. The decrease in 1854 was caused by the dryness of the season, which rendered it impossible to maintain the proper depth of water in the canal.

At length, the complaints of the coal and the iron trades, became so urgent, that the Committee of the Canal Company were compelled to take into consideration a plan which had frequently been pressed upon them by Mr. Freeth, their Secretary. This was the construction of a new canal and tunnel, on the Birmingham Level, from Netherton to Dudley Port. It was shown, that the distance between Netherton and Birmingham might be thus reduced 4 miles, and the ascent and descent of three locks be avoided; while owing to the increased size of the proposed tunnel, the passage of boats through it, could be rendered as easy and expeditious as on any other part of the canal. The highest ground

on the route was 354 feet above the water in the canal. In 1854, Mr. Walker was consulted, and in the following year, an Act authorising the construction of the works was carried through Parliament, and received the Royal assent in July, 1855. The drawings and specifications having been prepared by Messrs. Walker, Burges, and Cooper, the contract for the execution of the whole of the works was let, in November, to Mr. George Meakin, of Birkenhead. The Author was appointed the Resident Engineer, having under him seven inspectors of works, the chief of whom was James Sager. A Committee, of which Sir G. Nicholls, Bart., was the Chairman, had the direction of the undertaking. The first sod was turned by Lord Ward, at shaft No. 7, on the 28th of December, 1855. On the 17th of January, 1856, the sinking of the first shaft was commenced, and on the 19th of March, 1856, the excavation of the tunnel was begun, at shaft No. 15. On the 4th of April, the first brick in the tunnel was laid in the south side length, at shaft No. 15; and on the 25th of March, 1858, the last brick was laid by Mr. Walker, in the arch of the junction length, between shafts No. 7 and No. 8. On the 20th of August, 1858, the whole of the works were formally opened for traffic.

The time occupied in the construction of the tunnel, from the commencement of sinking the first shaft, to laying the last brick, was two years and seven months. The length of canal constructed is 2½ miles, comprising one quarter of a mile of embankment, half a mile of open cutting, and one mile and three quarters of tunnel. There are three embankments, containing, in all, 106,000 cubic yards, the greatest height being 26 feet. The embankments are, generally, 54 feet wide at the water level; but part of embankment No. 3 was made 66 feet wide at that level, to allow of an anticipated subsidence, which has since occurred, from the working of the mines underneath. The slopes of all the embankments were formed with an inclination of 2 to 1. There are four cuttings, from which the total quantity of earth removed, was 136,000 yards. Cuttings Nos. 1, 3, and 4, are 46 feet wide; and cutting No. 2 is 40 feet wide at the water level; the slopes in all cases being 1½ to 1. The materials excavated were, principally, clay and marl, which stood well at that slope, except in cutting No. 2, where an extensive slip occurred, which threatened to carry away a large pumping engine and to damage two coal pits, situated close to the top of the slope. This rendered necessary the construction of retaining walls in that cutting. The width of the waterway of the canal is 30 feet, except in cutting No. 2, where it is 24 feet. A towing path was formed on each side, 8 feet wide in the cuttings, and 12 feet wide on the embankments. The bottom and sides of the canal were lined with puddle, 2 feet thick in the

cuttings and 3 feet thick on the embankments; the puddle at the sides being carried up to 6 inches above the water level. The puddle was made with clay, spread in courses 8 inches thick, twice cut, and well trodden. The total quantity of puddle, including that used in the tunnel, was 53,000 cubic yards. On the puddle at the bottom, a layer of furnace cinders 6 inches thick was spread, the lower 4 inches being broken so as to pass through a ring 4 inches in diameter, and the remainder, which was mixed with fine ashes, so as to pass through a ring 2 inches in diameter. The thickness was increased at the sides to form a toe for the towing path walls. These cinders were intended to protect the puddle from injury by the boat hooks, &c., which, especially, on embankments, might cause serious damage. On these cinders the towing path walls, 2 feet 3 inches and 1 foot $10\frac{1}{2}$ inches thick, were built of brick; fine ashes, to the thickness of $4\frac{1}{2}$ inches and 9 inches, being introduced between the walls of the puddle at the sides. The walls were carried up to the water level, and on them were placed iron guards, $\frac{3}{4}$ths of an inch thick and 9 inches wide, cast in lengths of 12 feet. They were dovetailed into each other at the ends, and weighed 96 lbs. per yard. A lug was cast on each, projecting beyond the back of the wall, against which it was keyed up, by a cast-iron plate, 1 foot 6 inches long, and a wrought-iron key. Where the canal is curved, and where the walls are liable to be struck heavily by boats, the thickness of the brickwork was increased to 3 feet and 2 feet $7\frac{1}{2}$ inches, the guards being made 2 inches thick, and each being fastened down by two bolts, $1\frac{1}{4}$ inch square. These guards weigh from 290 lbs. to 400 lbs. per yard, and on them were bedded the coping bricks, 12 inches by 12 inches by $4\frac{1}{2}$ inches in section, rounded on the edge, and jointed in mortar. The coping is set back $3\frac{1}{2}$ inches from the front of the guard, but in exposed places it is increased to 7 inches, to avoid blows from the raking stems of the iron boats now in use.

The walls of the towing path being placed on new puddle, great care was necessary in their construction. A certain amount of settlement was unavoidable; but to render it as uniform as possible, the brickwork was built in long lengths, and not more than 18 inches in height at one time. It was then allowed to stand, for some days, before building another course. In order, also, to prevent the walls from being forced forward, by the pressure of the puddle at the sides, the water was, where practicable, gradually admitted into the canal, as the puddle was carried up. Where this could not be done, timber struts were placed from wall to wall, which were not removed until after the admission of the water. These precautions were absolutely necessary, while the walls and puddle were new; but after the work had set, they were not required. The water

has since been drawn out of several parts of the canal, without occasioning the slightest movement of the walls.

The towing paths were covered to a depth of 6 inches with well-burnt red ashes, from the puddling furnaces in the neighbourhood, which make an excellent and durable horse road.

Open channels were formed at the sides of the cuttings, which drain into the canal, through cast-iron pipes, 3 inches in diameter, provided for that purpose, at intervals of 100 feet. For the accommodation of the collieries and ironworks situated near the canal, seven basins, or docks, were made, varying in size from 300 feet by 33 feet to 75 feet by 24 feet. The construction of these basins is similar to that of the rest of the canal, except that timber wharfing is substituted for the iron guards and coping. This consists of two longitudinal fir planks, 11 inches by 3 inches in section, resting on oak sleepers, 8 feet 6 inches in length and 8 inches by 4 inches in section, placed 6 feet apart, with short sleepers in the intervals. The long sleepers are secured at the end to a T-piece and to two short piles. Instead of using bricks, the walls of two of these basins were built with cinders procured from the blast furnaces in the vicinity, and broken into pieces of convenient size. They were built in a species of rubble work, in courses about 2 feet high, large pieces being placed as binders. The cinders were solidly buried in mortar, and the walls were neatly pointed on the face. This material formed a substantial and durable wall, at about half the price of brickwork. The foundations of many of the bridges were carried up to the level of the ground with this material, and several of the retaining and fence walls were built with it.

Towing-path bridges were built over the entrances of three of these basins, the abutments and wing walls being built on the canal walls, which were strengthened for that purpose. The superstructure consists of two cast-iron girders, resting on stone imposts. The cast-iron covering plates are $\frac{3}{4}$ths of an inch in thickness, and are furnished with ribs 5 inches deep, secured to each other, and to the girders, by bolts $\frac{3}{4}$ths of an inch in diameter. The joints are caulked with iron cement. On the girders are built brick parapets 14 inches in thickness, finished with a semicircular brick coping. Four bridges, all of similar construction, were built to carry the roads over the canal. The bridge which carries the Birmingham and Sedgley Turnpike Road has two spans, of 42 feet 5 inches and 8 feet 7 inches, respectively. The pier and abutments are of brickwork, with stone imposts and coping. The girders are of cast iron placed 3 feet 10 inches apart, those for the larger opening being 47 feet in length, and 2 feet 3 inches in depth. Each girder weighs 6 tons 3 cwt., and was tested with a weight of $20\frac{1}{2}$ tons at

the centre, when the deflection was 0·96 inch, and the permanent set was 0·10 inch. The roadway plates are of cast iron, 3 feet 8 inches by 4 feet 6 inches and $\frac{3}{4}$ths of an inch thick, with ribs cast on them; they are secured to each other by bolts $\frac{3}{4}$ths of an inch in diameter, passing through the girders. The joints of the plates are caulked with bituminous cement. Brick parapets, 4 feet 6 inches in height above the road and 14 inches thick, were built on the face girders. Six bridges were built at the junctions, to carry the towing path across the canal. The spans vary from 39 feet to 50 feet. The abutments and wings are of brick, with stone quoins and imposts. The girders, which also form the parapets, were each cast in one piece, those for the span of 50 feet being 55 feet long and 3 feet 3 inches deep; each girder weighs 5 tons 8 cwt. The bridge, when put together, was tested with a weight of 26 tons equally distributed, under which the girders deflected $\frac{5}{8}$ths of an inch. On the bottom flanges of the girder are placed the cast-iron roadway plates, which are $\frac{3}{4}$ths of an inch thick, with ribs 5 inches deep, and are bolted to each other and to the girders, with bolts $\frac{3}{4}$ths of an inch in diameter. The joints are caulked with iron cement.

At Tividale, near the north end of the tunnel, the Wolverhampton Level Canal is carried over the new canal, on a brick aqueduct of three arches, two with a span of 19 feet, and the other, of 9 feet 3 inches. The waterway is 30 feet wide and 5 feet 6 inches deep, with a towing path 8 feet $10\frac{1}{2}$ inches in width on each side. The piers are 4 feet $1\frac{1}{2}$ inch, and the arches are 1 foot 6 inches thick. A layer of puddle, 2 feet thick, was carried over the arches, and the trough of the canal was completed as before described. At each end of the aqueduct, a cill and grooves were placed, to receive stop planks, whenever it may be required to draw the water out of the canal. The cills are of elm, 35 feet long and 1 foot 2 inches by 1 foot in section, bedded on and bolted down to a brick wall, 2 feet high, built for that purpose. The grooves are of cast iron, built into and bolted to the towing-path walls. The bottom of the canal is protected by an apron of bricks, laid on end, in cement, for a width of 8 feet on each side of the cill.

Near Dudley Port, the canal is carried over an occupation road, on a brick aqueduct 81 feet long. The span of the arch is 20 feet, with a versed sine of 7 feet; its thickness is 1 foot 6 inches. Under the Wolverhampton Level Aqueduct, there are two stop locks, each 87 feet long and 8 feet wide, with stop gates, cills, and grooves at each end. The locks are built of brick, with stone cutwaters, quoins, and coping. The gates are 9 feet $5\frac{1}{2}$ inches wide, 5 feet 10 inches high, and 9 inches thick. The framing of the gates is of oak, covered with fir planking 2 inches in thickness.

Each gate is furnished with a sluice and an elm paddle 1 foot 6 inches square. The hollow and clap quoins are of cast iron, $\frac{3}{4}$ths of an inch thick, secured to the stonework with split bolts.[1] The main cills are of oak, 15 inches by 10 inches in section, built into the brickwork. The clap cills, which are of elm, 9 inches by 8 inches in section, are secured to the main cills by screw bolts and plates. The recesses for the gates are covered with cast-iron plates, $\frac{3}{4}$ths of an inch thick, chequered on the top, and secured to the coping by split bolts. Each cutwater is protected by a strong iron guard, weighing 3 tons, cast in three pieces, and fastened down with bolts $1\frac{1}{2}$ inch square. The top of the pier is paved with bricks, laid on edge, in mortar. As all the boats are gauged in these locks, by toll-keepers stationed there for the purpose, an office was built on the pier, and booms are provided, which can be secured across the lock, to prevent the passage of boats during the absence of the toll-keepers; when not in use, these booms are floated back into recesses. There is also a swing plank to each lock, to enable the toll-keepers and boatmen to cross. These planks are of fir, 11 inches by 2 inches in section, bound with iron; they work on a pivot at one end, so as to swing freely, in either direction, when struck by a boat. Six stop cills were provided, so as to allow the water to be withdrawn from any part of the canal when required. Their construction is similar to those at the Wolverhampton Level Aqueduct previously described.

For the construction of the tunnel, seventeen shafts were sunk; those positions being selected which offered the greatest facilities, on the surface, for the deposit of spoil, &c. The distance between the shafts varied from 164 yards to 200 yards. Of this number, ten were merely intended for use during the construction of the tunnel; and seven were proposed to be left permanently open for ventilation. Four of the temporary shafts were lined with timber, and were 9 feet by 8 feet in the clear. The curbs, or settings, were of fir timber, 11 inches by 10 inches in section, placed 6 feet apart, and close boarded behind; these shafts were afterwards filled up. Six of the temporary shafts were lined with brickwork, the internal diameter being 8 feet. One of these was filled up on the completion of the tunnel, but the others were covered with cast-iron plates, about 5 feet below the surface. The permanent shafts were all lined with brickwork, 9 inches thick; one, which was worked with a horse gin, was 10 feet in diameter, and the others were 9 feet in diameter. The brick lining was supported on the arch of the tunnel by a cast-iron curb, weighing

[1] Cast-iron quoins have long been in use on the Birmingham Canal, and are found to be preferable to those of wood, or stone.

9 tons, in four pieces, strongly bolted together. Skewbacks were cast on the back of the curb, to receive the rings of the arch.

No attempt was made to 'coffer' out the water met with in the shafts. It is received in zinc gutters, nailed to the curbs, and is conducted by a cast-iron pipe, fixed down the inside of the shaft, and in a groove built in the soffit of the tunnel, to the back of the towing path, and under it into the canal. After the completion of the tunnel, the permanent shafts were carried up 12 feet above the surface, and were finished with a moulded brick cornice, and covered with a wrought-iron grating. The whole of the shafts were sunk by the ordinary method. The material having been removed to a depth varying according to the nature of the ground, an oak curb, 9 inches by 3 inches in section, was placed on the bottom, on which the brickwork was built. The excavation of the length below was then proceeded with, the curb being temporarily propped, until under-pinned by the brickwork brought up from the curb below. The brickwork of the shafts was laid in mortar, in alternate header and stretcher courses, the headers being moulded to the proper radius. Cement was only used in places where the ground was very wet. The total depth of all the shafts was 3,083 feet, of which 2,293 feet were lined with brickwork. The greatest depth of any of the shafts was 344 feet 6 inches, and the least depth was 65 feet 9 inches.

The average rate of progress, per day of twenty-four hours, from the commencement to the completion of each shaft, was 2 feet; but counting only the days on which work was actually done, it was 3 feet 4 inches. The ground was, principally, marl and 'bind;' but coal and basalt were met with in several of the shafts.

The tunnel is 3,036 yards, or nearly 1¾ mile long, 27 feet wide, and 24 feet 4 inches high in the clear. The waterway is 17 feet wide, 6 feet deep in the middle, and 5 feet at the sides. The height from the water level to the soffit of the tunnel is 15 feet 9 inches. The thickness of the brickwork of the tunnel is, generally, 1 foot 10½ inches in the walls and arch, and 1 foot 1½ inch in the invert; but in the side and shaft lengths, the walls and arch are 2 feet 3 inches thick. In places, also, where the ground was found to be bad, the thickness of the walls and arch was increased to 2 feet 3 inches, and of the invert, to 1 foot 6 inches and 1 foot 10½ inches.

The lengths of the various sections of tunnel as built, were:—

	Ft. In.		Ft. In.		Yards.
Walls and Arch	1 10½	Invert	1 1½	Length	2,467
„ „	1 10½	„	1 6	„	109
„ „	1 10½	„	1 10½	„	85
„ „	2 3	„	1 1½	„	375
		Total length		. .	3,036

It was, however, discovered, that in several places, where the foundation was 'blue bind,' or marl, the invert was forced up in the centre, owing to the swelling of the ground. This was not accompanied by any subsidence of the side walls; and although the brickwork was, in some parts, raised 5 inches, it was not broken, or crippled, except at a point immediately south of shaft No. 7. Here the invert having been forced up 8 inches in the centre, and some of the bricks crushed almost to powder, it was cut out and rebuilt 1 foot 10½ inches thick, for a length of 130 feet. This was done in short pieces, of about 6 feet at a time, the side walls being carefully strutted. In rebuilding a portion of this invert, 49 feet long, the versed sine was increased to 2 feet 6 inches.

The trough of the canal in the tunnel was formed in a similar way to that in the cuttings, the puddle at the bottom being covered, with broken cinders, to a depth of 6 inches. The towing-path walls, 1 foot 10½ inches thick, were protected by cast-iron guards, weighing 141 lbs. per yard. Each guard was held back by a wrought-iron tie, 1⅛ inch in diameter, to a cast-iron plate built into the wall of the tunnel. Sockets, 6 feet apart, were cast on the guards, into which were keyed the standards of the wrought-iron railing for protecting the towing path; this railing is 2 feet 8 inches high. The standards are 1¾ inch by 1¾ inch; the top rail is of half-round iron, 3 inches by 1½ inch, screwed down to the standards, and joined with a lap piece and two rivets. The lower rail is of round iron, 1½ inch in diameter, passing through and keyed into an eye forged in the standards, and joined at the ends by a wrought-iron screw ferule. The towing paths are covered with red ashes, to a depth of 6 inches.

As soon as the sinking of any shaft was completed, the excavation of a bottom heading, in each direction, was immediately commenced, and was proceeded with until it met that driven from the next shaft. The size of the heading was 5 feet by 3 feet, the bottom of it being level with the top of the intended invert. The construction of the tunnel was proceeded with, without waiting for the completion of the heading. The Author is glad to be able

to state, that no part of the tunnel was one inch out of the straight line; and when the water was admitted, the guards were found to be exactly level. This remark does not, however, now apply to a short piece of about 300 feet, at the south end of the tunnel, where, as early as June, 1857, it had been discovered and reported by the Author, that a subsidence was going on, from mining operations. Although these operations were immediately stopped, the sinking continued, so that at the date of opening, the tunnel was, at that place, about 10 inches lower than when it was built. The guard and towing path walls were, necessarily, raised accordingly. Similar depressions, although to a smaller extent, have also taken place near shafts No. 14 and No. 15.

The process of the excavation of a tunnel has been so minutely described by Mr. F. W. Simms, (M. Inst. C. E.,) in his work on "Practical Tunnelling,"[1] that it is unnecessary to repeat it here. The lengths excavated varied from 12 feet to 13 feet, and they were supported by timber in the usual way.

When the construction of the tunnel was proposed, a considerable diversity of opinion existed, as to the nature of the strata to be passed through. On the geological map, a mass of trap rock is shown, about a mile wide, at this point. This, which is locally called 'Rowley Rag,' is extensively quarried on the surface, for road metal and paving. It was, therefore, anticipated, that great expense would be incurred in excavating the tunnel; but in the borings, some of which were close to the summit, no trap whatever was met with. While the excavation of the shafts and tunnel was progressing, a careful record was kept of the strata passed through. With the exception of some apparently unconnected pieces, the only trap rock met with was a wall, or dyke, about 8 feet thick, a little to the north of shaft No. 7. From its inclination and position, this appeared to be the channel through which the trap rock had risen and spread over the surface. On the north side of the dyke, the strata were principally marl, coarse sand rock, and a hard shaly clay, locally called 'blue bind.' On the south side, marl and bind were likewise extensively met with; but coal, bat, ironstone, and fire clay were also passed through in several places.

The brickwork of the tunnel was laid in mortar; that of the side walls being built in old English bond, and that of the arch and invert in half brick rings, with headers where two courses coincided. The skewback of the invert was built with large bricks, moulded for that purpose. Five stop cills were placed in the

[1] *Vide* "Practical Tunnelling, &c." By F. W. Simms. 8vo. 2nd Edition. London, 1859.

tunnel, and one at each end, to enable the water to be withdrawn from any part, when required. The tunnel fronts were built entirely of brickwork, with curved and battering wing-walls. The face of the arch and the coping consist of large moulded bricks.

Nine men were killed, and eighteen were seriously injured during the construction of the tunnel. Of those killed, one fell down shaft No. 11, one was drowned in the sump of shaft No. 7, five were killed by skips, stones, &c., falling down the shafts, and two by stones, or materials falling on them while mining. Of those injured, two were drawn over the pulley at the top of shaft No. 10, owing to the carelessness of the engineman; eight were injured by stones, or materials falling on them while mining; four by skips, or materials falling down shafts on to them; two fell off the scaffolding, and two were hurt by the machinery on the surface.

The mortar used throughout the whole of the works was made with four parts of Hayhead lime, which is strongly hydraulic, measured before being slacked, four parts of sand, and one part of ashes. The lime was ground for twenty minutes under edge stones, during which time the sand, ashes, and water were added. Four mortar pans, driven by an engine of 20 H.P., were erected at Tividale, and two, driven by an engine of 12 H.P., at Windmill End. This mortar was found to set so satisfactorily, that cement was not used even in the tunnel, except where the work was required to set in a few hours. The cill walls, aprons, &c., were, generally, built in mortar, and the coping was set with it. The whole of the brickwork, except in the arches, was laid in alternate courses of header and stretcher on the face; all the inside work being of headers. The courses throughout were horizontal, splayed bricks being moulded for the fronts of the battering walls. Hoop-iron bond was used in some of the more important bridges. The total quantity of brickwork, including the tunnel, was about 75,000 cubic yards. The bricks used in the tunnel and throughout the works, except in the face work of the bridges, were Staffordshire brown bricks. Great care was taken, that only those of the best quality were brought on the works. A Table, showing the strength of these bricks, is given in the Appendix; (page 276). The pressure borne by each brick before crushing, varied from 14 tons to 31 tons, equal to an average of 75 tons per square foot. The bridges and tunnel fronts were faced with the best Staffordshire blue bricks. Some of the coping bricks were of unusual size, those on the tunnel fronts were 2 feet 3 inches by 1 foot 6 inches in section, and were believed to be the largest bricks ever made in Staffordshire. The stone used was principally a sandstone from Duke's Quarry, in Derbyshire.

In order to complete so large a work within the time specified, it was necessary for the Contractor to provide a considerable plant, and to make extensive arrangements for the supply and delivery of materials. A wharf was constructed on the old canal at Tividale, and another at Windmill End. For the conveyance of materials from these yards to the shafts, a tramway of the gauge of 2 feet 6 inches was laid over the whole length of the tunnel, with passing places and sidings at each shaft. Carpenters', smiths', and fitters' shops were also erected at Tividale.

The Paper is illustrated by a series of diagrams, and by a section of the strata passed through in constructing the tunnel.

[APPENDIX.

APPENDIX.

NETHERTON TUNNEL BRANCH, 1858.

EXPERIMENTS as to the power of BRICKS to resist a CRUSHING FORCE, applied by a HYDRAULIC PRESS.

Place of Manufacture.	Description.	Weight of one Brick.	Size of one Brick.	Surface exposed to Pressure.	Average Pressure when Crushing commenced.	Average Pressure, per Square Inch, when Crushing commenced.	Average Pressure, per Square Foot, when Crushing commenced.
		lbs.	Inches.	Tons.	Tons.	Tons.	Tons.
Old Hill . . .	Brown	9·78	$9\frac{1}{8} \times 4\frac{1}{4} \times 3\frac{1}{4}$	38·7	31	0·80	115
Tividale . . .	Blue	8·92	$8\frac{3}{4} \times 4\frac{1}{8} \times 3\frac{1}{4}$	36·09	22·5	0·62	89
Oldbury . . .	Brown	9·25	$9 \times 4\frac{1}{2} \times 3\frac{1}{4}$	40·50	20	0·50	72
Dudley Port .	Brown	9·58	$8\frac{1}{2} \times 4\frac{1}{4} \times 3\frac{1}{4}$	36·125	16·5	0·46	66
Oldbury . . .	Brown	9·53	$9 \times 4\frac{1}{4} \times 3\frac{1}{4}$	38·25	14	0·37	53
Netherton . .	Brown	9·78	$9 \times 4\frac{1}{4} \times 3\frac{1}{4}$	38·25	14	0·37	53
Stourbridge . .	Fire	7·25	$9 \times 4\frac{1}{2} \times 2\frac{1}{2}$	40·50	27	0·67	96

NOTE.—The Bricks were tested in pairs, with two thickesses of millboard between them and the press, and between each other. The Brick was assumed to have commenced crushing, on the first appearance of bursting, or shelling off.

[MR. LOCKE,

Mr. Locke, M.P., (Past-President,) said, this was a valuable Paper, and he wished more of the Members would imitate the example of the Author, and give the Institution the result of their experience. The construction of so extensive a tunnel, although it did not present any peculiar difficulties, was a work in which all must feel great interest. He regretted, however, that so favourable an opportunity had been lost, for placing upon record the entire stratification of the hill, as the great number of shafts afforded sufficient means of obtaining that information, and it would have materially increased the value of the Paper. Having the stratification of each shaft, it would not be difficult to fill up the intervening portions. Among the tunnels constructed under his direction, there was one on the Manchester and Sheffield Railway, longer than the Netherton Tunnel, but it did not present such peculiarities of stratification as were met with in the work under consideration. In the latter there was a superficial stratum of trap, and a small trap vein piercing through from below the tunnel, which, in the opinion of the Author, had been the feeder of the large overflow, or bed of trap, which lay on the surface, and it would have been desirable if the connection between the two had been traced, and exhibited, in section: sufficient data had, however, been given to show, that the assumed presence of trap rock need not deter Engineers, from making a tunnel in the localities where it existed.

The fact, that a tunnel of this extent, with so many shafts, had been constructed with less than an inch of deviation in the line, reflected the highest credit upon all engaged upon it. Although he had had some experience in tunnelling, he could not, in any case, boast of such accuracy as had been recorded in the present instance. In one of the first tunnels he constructed, at Liverpool, there was a deviation of 7 inches; but it was, fortunately, discovered in time to take advantage of the distance between the shafts, and the error was corrected before it was too late. He made this statement, in order that the younger Members of the profession might be induced to spare no pains, so to perfect their lines and levels as to render the chances of error the slightest possible; for where, as was often the case, the masonry of a tunnel had to follow quickly upon the mining operations, if both were not properly attended to, most important and serious consequences might arise.

Mr. J. R. Walker said, the section was merely a rough record of the strata passed through, in carrying out the works. He did not feel himself sufficiently conversant with geology, to be competent to fill up the vacancies between the shafts; he could only state, generally, that the whole of the ground was very much broken.

In reply to a question from the President, Mr. Walker stated, that the shafts and the tunnel had cost £155,000, and the total cost of the works, including the open canal, was £200,000.

Mr. BEARDMORE suggested, that the section of the hill should be sent to the Museum of Practical Geology, where means would, probably, be found, of filling in the portions between the shafts.

Mr. HEMANS had been particularly struck by the judicious and economical employment of the refuse of the blast furnaces in the foundations of the walls. The same principle might be carried out, where foundations were covered with earth, and protected against water, and that in many cases, hard chips, or rough concrete, such as was used in France, might be adopted with great advantage. Another subject for remark was the successful manner in which a tunnel of that length had been carried out with so flat an invert, considering the great width and the heavy pressure it had to sustain. The weight of the water, if it could be let in at an early stage, would keep down the invert; but he thought, in a tunnel of that nature, that greater curvature might have been advantageously given to the invert, for resisting the pressure. In this case, the invert had given way; for the bottom rose up for some distance, in consequence, as was presumed, of the swelling of the clay below the invert.

Mr. VIGNOLES expressed his high approbation of the great accuracy with which this tunnel had been constructed. Mr. Locke would not have forgotten the great success with which Mr. Purdon had executed the tunnel on the Manchester and Sheffield Line; although three miles in length, with only five shafts of great depth, the deviation was not more than one inch in line, and not a quarter of an inch in the level.

Mr. JAMES COOPER could vouch for the accuracy with which this work had been carried out, having had opportunities of testing it, by frequent inspections, during its progress. There was one point which had not been particularly mentioned, but which would have proved interesting to the Meeting; the difficulties frequently occasioned by the mining operations in the district, which were met with in the continuation of the embankment and the bridges, at the north and south ends. The bridges settled considerably during their construction, and the settlement had increased since their completion; but they were all designed with a view to meet the danger arising from this cause. The materials employed throughout the work, were of the cheapest description consistent with durability, and he considered the work had been very economically executed. Great care was exercised by the Resident Engineer and the inspectors, and great credit was due to them as well as to the Contractor, for the way in which the entire work was carried out. It would, certainly, be very desirable to have a more com-

plete record of the geological stratification of the Rowley Regis Hill, if it could be made with approximate correctness: but there was a difficulty in filling in the strata between the shafts, owing to the fault which had been referred to. The section, exhibited by Mr. Walker, was valuable, so far as it went, as being a faithful record of the strata actually passed through during the operations.

Mr. BATEMAN having been recently engaged in extensive works of the same description, in connection with the Glasgow Waterworks, involving the construction of thirteen miles of tunnels, comprising seventy separate tunnels and from forty to fifty shafts, felt considerable interest in the Paper, and was gratified at the extreme accuracy with which the tunnel had been driven. In the works to which he alluded, there were not less than two hundred junctions, yet it was impossible to tell the points of meeting, except by the different directions of the drill holes, so accurate had been the work, both as to line and level. The great difficulties met with in tunnelling, were those occasioned by water, quicksands, or treacherous material, and the most interesting accounts of that class of operations were those in which they had occurred. A very small amount of water had, it appeared, been encountered in the Netherton Tunnel; and where those difficulties had not to be contended with, tunnelling was a comparatively simple and easy operation, and both cost and time might be approximately estimated. In the construction of a tunnel for the Manchester Waterworks, a shaft was sunk 100 feet through a quicksand; black shale was then met with, through which the shaft was continued to a further depth of 50 feet. More than 1,000,000 gallons of water per day were pumped, for months together, from this shaft. The difficulty and cost attending these operations were also greatly increased, by the peculiar character of the country through which the tunnel was driven. In the Glasgow works no such difficulties were encountered; there it was a mere question of time and labour. In many cases, however, the rock was so hard, that not more than 3½ yards were excavated per month: an advance of 5 yards per month, was considered very good progress. He thought the value of the Paper would be enhanced, if it contained the relative cost of the work through the different descriptions of material. The character of the material was an important element, because where the ground was such, that a tunnel required a great quantity of timber, the cost would be considerably increased, in comparison with that of the tunnel, or those portions of it, where the material was sufficiently substantial not to require timbering.

In answer to several questions, Mr. Bateman said, that the tunnels to which he had alluded, were 8 feet in height, and 8 feet

in width. The aqueduct passed through a great variety of material. Beginning at Loch Katrine, low down geologically, in the mica slate, with beds of gneiss, it passed through the mica slate into clay slate, then across a thin bed of limestone, below the old red sandstone, into the conglomerate beds of the old red sandstone, and through all the upper and softer beds of the old red sandstone, into the carboniferous limestone and the coal measures. As an illustration of the entire freedom from water in the mica slate and clay slate formations, he might mention, that water had, occasionally, to be carried to wet the drill holes. The cost through the mica slate was about £12 per yard: and through the clay slate, £9, or £10 per yard. In the old red sandstone there was sufficient water to retard the progress, and he thought the cost in the lower beds of that stratum was about £10 per yard. The cost through the softer strata would be about £8 per yard, and in some cases, even less. This included the cost of the shafts, except where they were of considerable depth, and formed a heavy item. In one tunnel 2,300 yards in length, there were thirteen shafts, five of them being nearly 500 feet deep; those shafts were not included in the cost of tunnelling. Considerable portions of the tunnels were lined with brick, for in some places the rock, which was, at first, considered durable, was found to perish after exposure to the atmosphere; and the old red sandstone was also lined to a considerable extent. The cost of driving through soft material and of lining was, together, about equal to the cost through hard rock where no lining was required, and which was so compact, that water could neither penetrate nor escape.

Mr. Fowler, V.P., remarked, that the Paper contained so full a description of the work, and it had been so successfully executed, that it was difficult to find occasion for criticism. He had recently completed a tunnel, commenced by the late Mr. Brunel, on the Oxford, Worcester, and Wolverhampton Railway, in which the stratification was similar to that of the Netherton Tunnel, and where the same means were adopted and nearly the same materials were employed. He differed from the opinion, that greater curvature should have been given to the invert. The proof that it was sufficient, was afforded by the fact, that, in a total length of 1¾ mile, a rising of the invert had taken place for a length of only about 120 feet. For a tunnel carried through a variety of material, he thought this invert was judiciously designed, as it was better to make modifications where necessary, than to increase the weight of the invert throughout the whole length of the tunnel. It was desirable to know whether, after the tunnel was built, the spaces left in the excavation were filled in with brickwork, or had been left open.

Mr. J. R. Walker said, in reply, that the credit for the great

accuracy with which the design for the tunnel had been carried out, was not entirely due to the Resident Engineer, as with seventeen shafts and thirty-four faces at work, it was impossible for one person to see every profile set. The objection made to the flatness of the invert had been already answered; the success of the work justified the design. The higher the rise given to the invert, the greater would have been the quantity of puddle required to be filled in at the top. The rising of the invert occurred at a spot where it was laid upon the 'blue bind,' and was not discovered until some weeks after the invert was built, but no subsidence of the side walls had been occasioned by it. The quantity of water was considerable, in several of the shafts: in some cases it was drawn in buckets, but at shaft No. 8, an engine of 20 H. P. was kept at work. The cost of the tunnel was £50 per yard forward. The sum of £155,000 placed to the charge of the tunnel, included the tunnel faces and the shafts. The cost of the tunnel alone, of that section, would be £39. 5*s.* per yard forward; with canal and side walls, it would be £45. 5*s.* per yard. The material was of such a nature as to require, that the arch should be closely timbered throughout. The spaces left in the excavation had been filled up, either by solid brickwork, or by earth rammed in. As to the suggestion of sending the section to the Museum of Practical Geology to have the spaces between the shafts filled up, he stated, that he had already shown it to Mr. Jukes, the former geological surveyor of the district, and had given him all the information he desired upon the subject.

Mr. Bidder,—President,—had great pleasure in adding his testimony to that which had already been given, as to the practical value of the Paper; it bore evidence of very careful preparation, and would be of great use to many Members who might be engaged, hereafter, upon similar works. But it was to be remarked, that every tunnel had its own peculiar history: and his experience had taught him, that however simple the work might appear at first, however sure the Engineer might consider himself of the material he had to work upon, yet, in execution, difficulties were continually occurring which could not be foreseen in the estimates, and which might ruin the Contractor. There were many present whose experience with regard to the contingencies met with in tunnelling, would be very valuable to the Institution; contingencies which required all the resources of mechanical art, all the experience of Civil Engineers, and all the enterprise of Contractors to bring the works to a successful result. He hoped, therefore, that this would not be the only Paper upon that highly interesting subject. The tunnel which was the subject of the Paper, had been admirably designed and executed, and it reflected the highest credit upon all engaged in it. It was remarkable for its extraor-

dinary freedom from natural casualties; none had occurred, except the rising of a small portion of the invert, attributed to the swelling of the clay below. The cost also of its construction had been unusually small, only £50 per yard, including the canal inside, for which £6 per yard should be deducted. Both the railway and the canal works were subject to the effects of the extensive mining operations carried on in the district, so that the Engineer must determine, either to construct his works in such a manner as to admit of the mines being worked, or submit to heavy exactions from the coal owners. In North Staffordshire, it was not only necessary to purchase the width of land required for the works, but also, thirty yards beyond, on each side, to be secure from the effects of mining operations. On that railway, the bridges were constructed with upright sides and iron girders, so that, in the event of subsidence, they could be easily re-adjusted.

February 14, 1860.

GEORGE PARKER BIDDER, President, in the Chair.

No. 1,014.—"On the Construction of Artillery, and other Vessels, to resist great internal pressure."[1] By JAMES ATKINSON LONGRIDGE, M. Inst. C.E.

IN bringing before the Institution the subject of the present Paper, the Author wishes, in the outset, to define the limits within which he conceives the Civil Engineer may fairly work, without trenching upon the field of his military brethren.

Not only in the present day, when the profession of the Civil Engineer has risen to an importance second to no other, but even in its infancy, those who followed that and its cognate pursuits, have distinguished themselves by their inquiries and experiments on this subject; and when it is borne in mind, that the names of Robins and Hutton in bygone times, and recently, those of Nasmyth, Whitworth, Mallet, and Armstrong are intimately connected with the mechanism of warfare, the Author feels that he is not going too far, in bringing the subject forward for the consideration of the Members of this Institution.

He does not propose to make a complete survey of the very wide field which contains the science of gunnery; but to confine himself to a small portion of it. Small as that is, it appears to him to be the foundation of the whole; for however perfect may be the theory, and however expert the practitioner, it is the amount of force at his disposal which must limit his efficiency, and unless he can command this force in sufficient quantity and intensity, the results will ever fall short of his desires.

The invention of gunpowder, and more recently of gun cotton, gives a source of enormous power, but unless that power be controlled, its full value can never be utilised; and striving after greater and still greater effects, the probable result may be, that the Engineer will be "hoist with his own petard."

The first point, then, in the science of gunnery, and that which

[1] The discussion upon this Paper extended over six evenings, but an abstract of the whole is given consecutively.

limits its future, appears to be, the construction of guns of sufficient strength to curb and govern the utmost force of the explosive compound which may be used in them.

So long as gunpowder can burst guns and mortars, so long it is unmanageable, and wanting in that perfect obedience which is the first principle of effective service.

Therefore, leaving aside, for the present, all the other interesting and important questions which meet the Military Engineer on every hand, during his onward way, the Author proposes to limit himself to the investigation of the method of making a gun, which shall give the gunner the mastery over gunpowder;—in other words, a gun which gunpowder cannot burst.

And this is a question, which, in his opinion, no one is more able to deal with than the Civil Engineer of the present day. Exercised in the application of metal to purposes of construction,—with experience still limited and greatly below what is desirable, yet an experience which a few years ago was non-existent,—the Civil Engineer should be more conversant with the properties of the useful metals, than his military brethren. And when, moreover, it is remembered, that structures requiring for their success, an intimate knowledge of these properties, have of late become realities, such as the Britannia, the Victoria and the Saltash Bridges, and the Great Eastern Steamship, there may be fairly claimed for the Civil Engineer, such an acquaintance with the use of metal as to justify him in discussing the question, how to make a strong and effective gun.

The attention of the Author was drawn to this subject early in 1855. He was previously aware of the difficulty, experienced by manufacturers of hydraulic presses, in making cylinders of large size to resist the moderate pressure of 3 tons, or 4 tons per square inch; and in common with others, he knew the explanation thereof, first given, as he believes, by Professor Barlow, (Hon. M. Inst. C.E.,) with the clearness which distinguishes all the works of that accomplished mathematician.

Fully satisfied of the general correctness of Professor Barlow's views, the Author was led to consider, how the inherent defect of any gun composed of material more, or less homogeneous, such as cast iron, or gun metal, could be remedied. He was not long in concluding, that the object to be attained, was to construct a vessel in such an initial state of equilibrium, that when the varying strain caused by the internal pressure should come upon it, the initial strain should be, as it were, complementary to the induced strain, and the sum of the two should be constant throughout.

Supposing the strain caused by the explosion to be some function of the distance from the centre, it was first necessary to

ascertain the nature of this function, and then to find a mode of construction, such that the state of the particles before the explosion, should make up the difference between the strain so determined and the constant tensile force of the material employed.

It was evident, that neither cast metal, nor forged metal in mass could possess the required properties. The Author at once saw, that the best chance was, in putting on layer after layer and giving to each the due initial tensile strain. This he thought might be nearly accomplished, by wrapping the successive layers of wire round an internal core and coiling them on with the proper tension. The facility of execution of such an idea was greatly in its favour, and the Author proceeded, as soon as circumstances permitted, to submit it to experiment. The result of these experiments, which will be hereafter given in detail, was to his mind so satisfactory, that he lost no time in bringing the matter before Lord Panmure, then Secretary at War, and as usual, the proposition was referred to the Select Committee at Woolwich.

The Author submitted his views to that tribunal, as well as he was able, during the short interview he had with it, and left a brass cylinder covered with wire, with the request that it might be fairly tried, as to its power of endurance.

His request was partially acceded to, but other engagements prevented him from being present at the trial, and, as will be hereafter fully explained, the result was, not that the cylinder was burst, but that the end was blown off, owing entirely to the method of conducting the experiment.

It is due to Lieut. Colonel Eardley Wilmot, under whom the experiment was conducted, to state, that he expressed to the Author his opinion, that the result was in no degree decisive as to the principle, and that he felt anxious to see further experiments.

The Author however found it not so easy to accomplish this. He urged upon the authorities the advisability of making further experiments, and offered to construct a gun on this principle, the whole expense of which he would guarantee should not exceed a very limited amount. It was, however, in vain. On the 25th of October, 1855, he was informed that the matter had been referred back to the Select Committee, and that they did not consider it desirable, that further experiments should be made on guns so constructed.

The Author finding no chance of obtaining such a trial as he desired, continued the experiments for his own satisfaction, until he was convinced, that the requirements of the theory were capable of practical realisation.

It was about this time, that he was called upon by Captain Blakely, who had then, and has since, devoted both time and money to the development of the same principle; although, at that period, Captain Blakely appeared to consider the practical solution

was by means of concentric rings, or hoops shrunk, or forced on, in successive layers over a central shell.

At the same time, although unknown to the Author, Mr. Mallet, (M. Inst. C.E.,) was engaged in devising and constructing mortars on the same principle, and was assisted in his calculations by the mathematical ability of Professor Hart, of Dublin.

Mr. (now Sir William) Armstrong, (M. Inst. C.E.,) was also engaged in the construction of a gun, depending for its strength upon external concentric layers; but the Author believes he did not then attach them under the varying initial tensions, which form the essential feature of the mode of construction advocated in this Paper.

And here it may be stated, by way of saving the time of the Institution, both now and during the discussion which may arise, that the principle brought forward is not simply that of strengthening guns by outer hoops. This mode of construction is probably the most ancient of all, and many specimens of it are to be met with, not only in Europe but in India and in China. It was subsequently abandoned, when the art of casting arrived at greater perfection, and has since only been reverted to as a means of strengthening cast-metal guns.

The principle alluded to is that of building up a gun, layer by layer, and in such manner, that each successive layer, proceeding outwards from the centre, shall be laid on with a tension exceeding that of those below it; so that in fact, the inner layers are in their normal state, in compression. It is to the validity of this principle, that the Author particularly invites discussion.

It has already been said, that the problem to be solved, is to make a gun that cannot be burst by gunpowder.

The first information required, is, therefore, an answer to the question,—what is the ultimate force of gunpowder; that is to say, supposing a close vessel to be filled with gunpowder and the gunpowder then exploded, without means of exit, what will be the pressure within the vessel?

According to Robins, the ultimate strength of gunpowder was valued at 1,000 atmospheres, or nearly 7 tons per square inch.

By Dr. Hutton, it was carried as far as 2,000 to 2,400 atmospheres, or from 14 tons to 17 tons per square inch.

It seemed, however, desirable to the Author, to ascertain, for himself, this important point. It occurred to him, that the most satisfactory way of doing this, was to prepare vessels of certain known strengths, then to fill them with powder, and having plugged them up so as to prevent escape, to fire the powder in the inside. He therefore made application for a quantity of Government cannon powder, and had a series of thin cast-iron cylinders prepared, each 1 inch in diameter, and $\frac{1}{10}$th of an inch thick. These were bored and turned, so as to be exactly of the same dimensions,

and were purposely made of very hard and brittle iron, so as of themselves to give the minimum of strength. These cylinders were wrapped round with iron wire, the tensile strength of which was ascertained by actual experiment. The number of coils varied according to the degree of strength required, and each coil was laid on with the initial strain, which the Author's calculations led him to believe would, at the moment of bursting, cause all the coils to give way together.

These cylinders were filled with powder and the ends secured, leaving no vent, beyond a touch hole, the size of a small pin, through which the powder was exploded. Several of these, of course, burst, but at length it was found, that a cylinder, as above described, with ten coils of wire upon it, could not be burst.[1]

Now the diametral section of the cast iron is $\frac{2}{10}$ths of an inch, and taking its strength at 8 tons per square inch the result is :—

	Tons.
$\cdot\frac{2}{10}$ths of an inch $\times$ 8 tons per square inch =	1·6
There were ten coils of wire, each wire by experiment broke with 60 lbs., and was $\frac{1}{28}$th inch in diameter, therefore the tensile strength of the two sides = $2 \times 28 \times 60 \times 10 \div 2240$ =	15·0
Total strength . .	16·6

The internal diameter of the cylinder was exactly 1 inch; consequently it appears, that the ultimate strength of the powder did not exceed 17 tons per square inch.

The Author would, however, wish it to be understood, that he does not hold this to be the maximum effect that may be produced. The explosion of powder is more of an impact than a pressure, and although, strictly speaking, impact is only a pressure of short duration, the question of the length of this duration is generally admitted to have great influence upon the effect produced.

For instance, Professor Rankine states, that "a bar, to resist with safety the sudden application of a given pull, requires to have twice the strength that is necessary to resist the gradual application and steady action of the same pull."[2]

This being so, it follows, that the more rapid the explosion, the greater is the strain on the gun. Not, probably, that the ultimate pressure is any greater, but that being produced in less time, its effect is greater. This is, probably, the cause of guns being more liable to burst when they get hot. It is not that the iron is

[1] One of these cylinders was exhibited.—EDITOR.

[2] *Vide* "Manual of Applied Mechanics," p. 287.

weaker, for Mr. Fairbairn, (M. Inst. C.E.,) has shown, that up to 600° the strength of cast iron is not materially diminished; but when the gun is heated, the gunpowder gets warmed and burns more rapidly, and the force is generated and applied more suddenly.

Therefore, although the Author found, that the bursting effect of cannon powder did not exceed 17 tons per square inch, he is willing to admit, that it may, under peculiar circumstances, exert a greater force. At any rate it seems to him, that if it is sought to make the most of the force of gunpowder, the vessels in which it is employed should be capable of resisting, at least, this strain.[1]

According to Professor Barlow's theory, no vessel, however thick, can permanently resist an internal strain greater than the tensile strength of the material. This being so, and the tensile strength of cast iron being about 8 tons per square inch, it is hopeless to look to that material for such strength as is required; and it does seem strange, that the use of this material should be persisted in, and that experiment after experiment should be made, in search of that which is as impossible to be found as the philosopher's stone, viz., a means to make cast iron alone, endure more than its ultimate strength.

It may be true, as was remarked to the Author, by a military officer of high position, that formerly, guns did not burst as they now do. Possibly, guns in those days had not the same amount of work to do? The first rails laid on the Liverpool and Manchester Railway weighed about 35 lbs. per yard, and they did their work well, for a time; but when heavier engines and greater speeds were arrived at, heavier rails were required; and so it is with guns. Much greater care is now taken in testing the purity of the component materials of gunpowder, and therefore, it is probable, if not certain, that the rapidity of combustion must be greater. This, and the increased size of guns, will easily account for the greater number of casualties, without seeking for the cause, either in the assumed deterioration of iron, or the asserted dishonesty of contractors.

The Author is not disposed to think, that either the strength of English iron, or the honesty of English contractors is less, than in what used to be termed the good old days of the war; but he does think, that the strength of powder is greater and the results sought from it much greater, than in former days.

Therefore, without expressing any opinion on the policy of creating Government establishments for construction, he would raise his voice against the assertion, that such were rendered necessary by either the incapacity, or the dishonesty of private firms.

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[1] *Vide* Note on the Strength of Powder in the Appendix, p. 322.

It has been stated, that no 68-pounder in the service can be fired, with safety, with a full charge of powder. It is, further, a matter of notoriety that several of the Lancaster guns were burst. Of the Sweaborg 13-inch mortars it is needless to speak. All this ought to prove, that cast iron has been taxed beyond its strength. As this does not seem to be universally admitted, it is necessary, before proceeding with the peculiar subject of this Paper, to say a few words on the causes of failure of cast-iron guns.

In the first place, the actual strength of the interior of a large gun, or mortar, is far below that of the average of ordinary castings, and always must be so, whilst guns are cast solid. So long as this is the case, the outside must cool and solidify first, whilst the interior, cooling more slowly, must be drawn and be rendered less dense, and consequently, *cæteris paribus*, less resisting. This is an operation of nature which no care in selecting material can overcome.

The worst part of this iron, in the chase of the gun, is afterwards bored out; but still the metal around the internal circumference is weakened below the average, and at the bottom of the powder chamber it is in the very worst possible condition. The sudden changes of dimensions, at various parts of the gun, are also sources of weakness, as has been pointed out by Mr. Mallet,[1] who bases his views upon the theory, that the principal axes of the crystals arrange themselves in the direction of the flow of heat outwards, and that whenever re-entering angles, or sudden changes of dimensions occur, planes of weakness are thereby produced.

This explanation depends too much upon, what appear to the Author to be, arbitrary assumptions, to enable him to place much confidence in it. He has examined carefully many cases of fracture of cast iron, but in no instance has he been able to satisfy himself, that the crystals have that definite direction which would justify him in determining thereby, a plane of weakness. They have always appeared to be a confused mass of more, or less, defined crystals, but certainly not so arranged, that he could ascertain any uniform direction of what Mr. Mallet calls their principal axes.

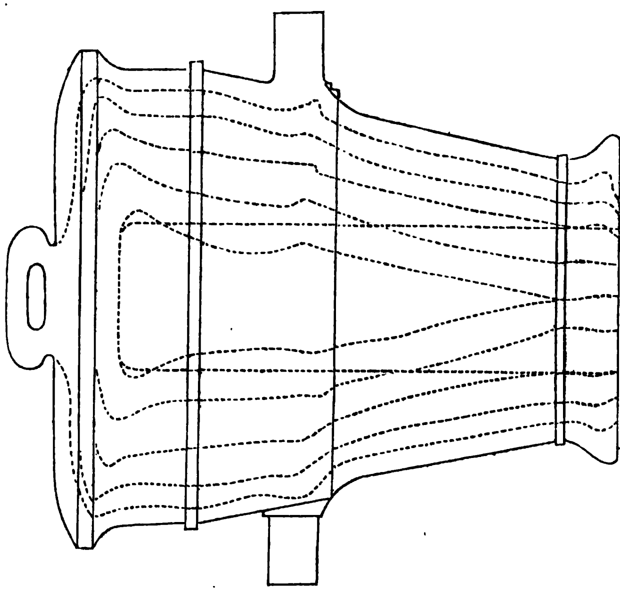
The Author thinks, that without having recourse to this theory, the law of cooling alone will fully account for the source of weakness in the cases in question. Whenever a variation in thickness occurs, a difference in the rate of cooling must also take place. This alone must give rise to a state of varied stress, amongst the particles of the metal, which, without doubt, diminishes its effi-

[1] *Vide* "On the Physical Conditions involved in the Construction of Artillery." By R. Mallet. 4to. Dublin, 1856.

ciency as a resisting substance. In ordinary castings this is too well understood and admitted, to require further remark. But the same law operates in guns, though, perhaps, to a less obvious extent.

Take, for instance, the accompanying sketch of a gun, (Fig. 1,) distorted in its proportions, for the sake of illustration, and sup-

Fig. 1.



pose it to have cooled down after casting. Although, in the present state of knowledge of the subject, it would be impossible to determine the absolute position of the isothermal lines, at any period of cooling, yet it is certain, they must approximate to the dotted lines, shown in the sketch; and following these lines according to some definite law, would be the lines of equal stress of the particles of the gun, when cold.

When, therefore, the gun is bored out, it is evident, that the inner circumference of the bore must be in a state of varying strain, and that strain is one of tension. Consequently, the internal part of the gun is, throughout, in an initial state of more, or less tension; and as regards its power to resist a tensile strain, it is inferior to the normal, or average strength of the material.

But beyond this, whenever a change of dimensions occurs, the cooling will give rise to varying strains, which may account for fracture taking place, at those particular places.

The Author does not, however, propose to follow this subject further. His main object is to show, that the inner portion of a gun, which has the greatest strain to resist, is by the process of construction, already weakened below the average strength of the material. How much below, he does not pretend to say, but a few well-devised experiments would throw great light on the subject.

The Blue Book recently issued, records the results of the experiments conducted by Lieut. Colonel Eardley Wilmot, at Woolwich. It contains a mass of information respecting the properties of a certain number of irons, but is altogether silent upon this most important element in the question of the use of these irons, in the construction of guns. The Author, therefore, contents himself with the statement of the fact, that the strength of the material next the inner circumference, is below the average strength of that material, as shown by experiments recorded in the Blue Book in question.

The next point to be considered, is the amount of strain to which guns are now subjected. In former days, guns were generally of less calibre, the powder was slower in combustion, and the windage was probably greater. But beyond all this, the modern introduction of the principle of elongated, instead of round shot, and of rifling, has to be taken into account.

A long shot has much more inertia, in proportion to its diameter, and to obtain the full benefit of rifling, it must fit tightly within the gun. Thus there is an increase of inertia and of friction, with a decrease of windage. The result is, that the shot is displaced more slowly, and the pressure of the powder behind is greatly increased; and, as practice shows, it is increased to such an extent, that the guns cannot bear it. Another point, not to be overlooked, is the increase of range, that is, of initial velocity, sought for in the present day. Under the old system, it is well known, the range was necessarily very limited. If the charge of powder was increased, beyond a certain point, the range was but slightly extended, for the simple reason, that as soon as the inertia of the ball was overcome, it moved forward and prevented the back pressure from accumulating; and it often happened, that part of the powder was actually blown out of the gun in an unconsumed state. But with a long tight-fitting, rifled shot, the pressure accumulates, to an extent previously unknown.

Enough has probably been said, to explain why it is, that guns, which formerly stood well, are incapable of resisting the strain now put upon them. The Author will only further observe, that it does seem to him remarkable, that persistent efforts should be still made, to do that which experience had shown to be impossible.

Guns of the ordinary construction have been handed over to mechanicians of the greatest ability, to be rifled. The Author

ventures to predict, that utter failure will be the result. They were scarcely strong enough to bear their old work, and must inevitably give way, when a vastly increased strain is put upon them. The fact of cast-iron guns failing has, however, become admitted; but, unfortunately only so far, that the failure has been laid at the door, either of inferiority of material, or of dishonesty of purpose. As a result, a national Gun Foundry has been established, at enormous expense, for the express purpose of making cast-iron guns.[1]

The Author does not doubt, that by great care in selecting and manufacturing the best material, results may, perhaps, be arrived at superior to the average under the old system. At the same time he feels, and believes, that many will participate in the feeling, that a new establishment of any description must always labour under disadvantage, when compared with old-established firms, who having obtained a reputation, and having abundant means at their command, are actuated quite as much by the wish to maintain that reputation, as by the desire of making money. Such firms know well, that their power of money-making depends on keeping up their character; and though the former is the essence of all commercial transactions, it is very far from being antagonistic to the production of a first-rate article.

To return to the subject. Cast iron has been tried and found wanting. The initiative, in seeking a new material, has not been taken by Government establishments, but by private individuals, who have devoted much time and money to the subject.

Wrought iron and steel have been tried, and in point of workmanship magnificent results are arrived at, though at enormous expense, as regards large guns. Taking the tensile force of the one at 20 tons and of the other at 40 tons per square inch, and the force of gunpowder, as above stated, at 15 tons, it would appear, that either of these materials would comply with Professor Barlow's requirements. But in practice is it so? Upon this, the Author is not able to pronounce a definite opinion; but the same objections apply, as to guns of cast iron, viz., that the inner part of the gun must be in a state of initial tension. The expense and difficulty of manufacture are, also, very great.

As the finest specimen of that kind of manufacture, the steel gun forged by M. Krüpp, and afterwards bored and mounted in a cast-iron jacket at Woolwich, may be instanced. That gun is stated by Mr. Mallet[2] to have been bored out to 8 inches, and to have been from 4 inches to 4½ inches thick. Taking the tensile force of hammered cast steel at 40 tons per square inch, the resist-

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[1] This was written in November, 1859.—AUTHOR.

[2] *Vide* Mallet's "Construction of Artillery, &c.," Appendix, p. 235.

ance would be from 320 tons to 360 tons, which, if the strain had been uniform throughout, would have been equal to between 40 tons and 45 tons per square inch, on the diameter; yet the gun burst at the first discharge, with 25 lbs. of powder and a 260-lbs. shot.

Mr. Mallet next mentions a wrought-iron 8-inch gun, forged at the Gospel Oak Ironworks, and proved at Woolwich, on the 12th of July, 1855, which burst into several pieces at the first discharge. This gun is stated to have been of very nearly the same dimensions as the established cast-iron guns of the same calibre. The thickness at the breech end was, therefore, about 9 inches; and taking the tensile force at 20 tons per square inch, the material, provided it had been uniformly strained, ought to have resisted a diametral strain of 360 tons, or about 45 tons per square inch. This gun, which to the eye, presented, both externally and internally, an appearance of entire soundness and perfection of material, burst with a proof charge of 28 lbs. of powder and two spherical 8-inch shot.

The next gun spoken of by Mr. Mallet is that which burst on board the United States frigate, 'Princeton,' in 1842, or 1843. He gives the very interesting Report of the Committee of the Franklin Institute on this gun, and on the material of which it was made. Amongst other experiments, were those made to determine its tensile strength. First, in the original bar; secondly, in a bar cut from interior of the gun; thirdly, in a bar made from a portion of the gun, re-worked under the hammer.

The mean tensile strength per square inch of the original bar was:—

1st Bar	46,086 lbs.
2nd „	38,595 „
3rd „	52,521 „

Other experiments made from the same iron gave the following results:—

"1. The average tensile force with which the specimens from the interior of the gun broke, when strained in the direction of the fibre, is less than	32,100 lbs.
2. The specimen from the interior, strained in a direction across the fibre, gave	23,700 „
3. The specimens from the outside of the gun, across the fibre, gave an average of less than	45,333 „
4. Annealed specimens from the interior, strained lengthwise of the fibre, gave an average of	36,067 „

5. The average of all the specimens from the gun, not hammered, is	33,300 lbs.
6. The average of the specimens worked down under the hammer, is	63,475 „

"The general conclusions, from these results, are the same as those from the experiments made by the Committee in Boston, so far as the two series can be compared.

"1. The average strength of the iron, as it existed in the gun, from both series, is . .	33,586 lbs.
2. The average strength of the iron from the gun, after being drawn down with the hammer, from both series, is	59,824 „
3. The average strength of the original bars from the experiments of the first series, is .	46,950 „ "

Consequently, taking the original strength as 100, that of the average of the iron, as existing in the gun, was 72, showing a deterioration of 28 per cent.; and if the tensile force of the interior is taken, when strained in a direction across the fibres, that being the actual direction of the strain in the gun, the proportion to the original bar is as 50 to 100, or a deterioration of 50 per cent.

The Committee state, in conclusion, their "opinion, that, in the present state of the arts [in 1844], the use of wrought-iron guns of large calibre, made on the same plan as the gun now under examination, ought to be abandoned, for the following reasons:—

"1. The practical difficulty, if not impossibility, of welding such a large mass of iron, so as to insure perfect soundness and uniformity throughout.
2. The uncertainty, that will always prevail, in regard to imperfections in the welding; and
3. From the fact, that iron decreases very much in strength, from the long exposure to the intense heat necessary in making a gun of this size, without a possibility, with the hammers at present in use in this country [in America], of restoring the fibre by hammering."

The Author, though dissenting from the views expressed in the last paragraph, inasmuch as he does not believe that long exposure to heat alone will deteriorate the iron, nor that any amount of hammering will restore its fibre, is inclined to agree with the two first reasons, for abandoning the construction of forged wrought-iron guns of large dimensions.

It is true, that the Mersey Iron Company, by great skill, and a thorough knowledge of their trade, and by the appliances at their command, have succeeded in forging the magnificent gun which, with a liberality equal to their enterprise, they presented to the nation. But so far as the Author knows, that gun is as yet only an

experiment; and he has even seen it stated, that already it is beginning to show symptoms of cracking in the interior.

Speaking of wrought-iron guns, Mr. Mallet says:—[1] "The facts [which he has previously stated] are worthy of notice, as indicating the absolute uncertainty that ever must exist as to the trustworthiness of wrought-iron guns, forged in one great mass, although executed without regard to cost, and by parties anxious faithfully to produce a result of the highest excellence. Some of the evils incident to this gun might have been avoided by greater experience and judgment; but the main evil is inherent, and inseparable from every huge forging, and most so where the weldings are most numerous."

On the other hand it should be mentioned, that Mr. Clay, of the Mersey Iron Works, differs from Mr. Mallet, and very justly observes, that "the several failures in the manufacture of wrought-iron guns should not be a matter of surprise; for it is hardly reasonable to expect immediate success in any new fabrication."[2]

Mr. Clay, in the same publication, gives an account of experiments to determine the tensile strength of the iron from which the monster gun was made, and of the same iron, after manufacture into the gun. The results were as follows:—

"Experiment.	Description of Iron.		Breaking strain in lbs. per sq. in.	Average.
No. 1.	Original iron of which the gun was made		48,384	49,504
No. 2.	Ditto	ditto	50,624	
No. 3.	Cut across the grain from muzzle of gun		41,644	43,390
No. 4.	Ditto	ditto	43,904	
No. 5.	Ditto	ditto	50,624	
No. 6.	Cut with the grain from muzzle of gun		48,384	50,624
No. 7.	Ditto	ditto	50,624	
No. 8.	Ditto	ditto	52,864	
No. 9.	Borings from gun re-worked with coal		60,584	61,704
No. 10.	Ditto	ditto	62,824	
No. 11.	Borings from gun re-worked with charcoal		76,584	76,584
No. 12.	Swedish iron as imported, $\frac{3}{4}$ inch square		60,584	60,584"

Taking the average of the first two experiments, and comparing it with that of the following three, there is a decrease of strength of about 13 per cent., whilst on the other hand, as compared with

[1] *Vide* Mallet's "Construction of Artillery, &c.," page 239.
[2] *Vide* Orr's "Circle of the Industrial Arts," page 331.

the 6th, 7th, and 8th, there is a gain of strength of 2 per cent. These experiments are not, however, so conclusive as those previously quoted, as the iron was cut from the muzzle of the gun, and not from the interior, at the breech, where the thickness is greatest, and the deterioration is, necessarily, the most.

To sum up this part of the question, the Author is, perhaps, justified in saying, that the manufacture of large forged wrought-iron guns is an operation of great difficulty, expense, and uncertainty, and however the difficulty and expense may be decreased, the uncertainty must still remain. Moreover, at the best, it is but substituting for cast iron a material of a higher tensile strength; the radical defect of a homogeneous mass still remaining, viz., the unequal distribution of the strain, from the inner to the outer circumference. The same remarks apply, with still greater force, to guns of hammered cast steel of large dimensions.

The Author has already pointed out the principle, which appears to be the basis of a sound and reliable construction. It is that of manufacturing the gun of successive layers, laid on with an original increasing strain from the centre to the circumference.

The Author claims no exclusive merit for this idea. It appears to have been entertained both by Mr. Mallet and Captain Blakely, and perhaps by others. In 1855, when he mentioned the principle to Sir William Armstrong, and described the method he proposed for carrying it into effect, by means of wire, that gentleman said, Mr. Brunel had also entertained the same idea, and had spoken to him with reference to making a gun on this principle; but finding that the Author was already engaged on it, he had dropped the subject.

Leaving, therefore, aside the generally unimportant and always unsatisfactory inquiry as to priority of invention, the Author will describe his own course of proceeding, commenced in entire ignorance of what others either had done, or were doing.

In the outset, the Author foresaw great practical difficulty in the use of hoops, whether shrunk on, or forced on. Since then, the subject has been investigated mathematically by Dr. Hart, and more recently, at the Author's request, by Mr. C. H. Brooks, as given in the Appendix, (page 329,) to whose results attention is directed.

In the first place, then, there is an objection to the use of hoops from the want of continuity. The special requirement is, that each layer of the gun shall be in a definite initial state of tension, or compression, previous to explosion. If in Fig. 2, (page 297,) A B C D, represent a portion of a section of an 8-inch gun, of which A G B is the inner, and D F C, the outer circumference, the state of tension of any particle between G and F may be denoted by ordinates drawn at the points in question, those above G F representing tension, and those below, compression.

Fig. 2.

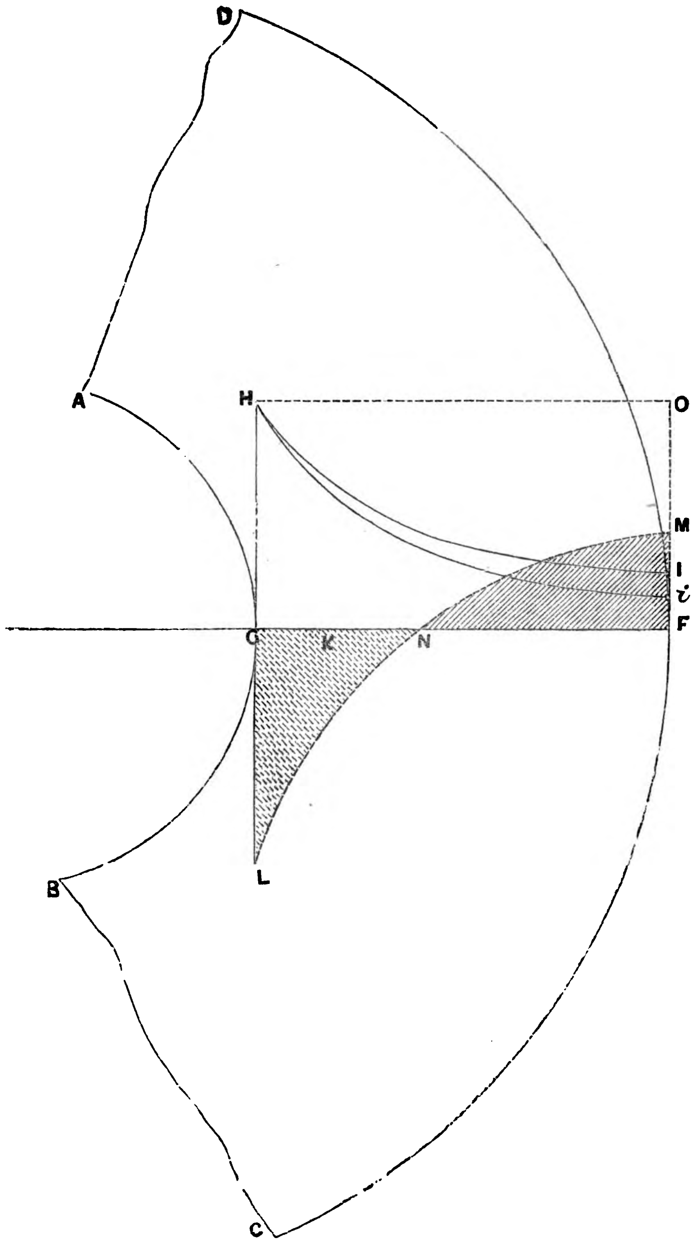


Fig. 3.

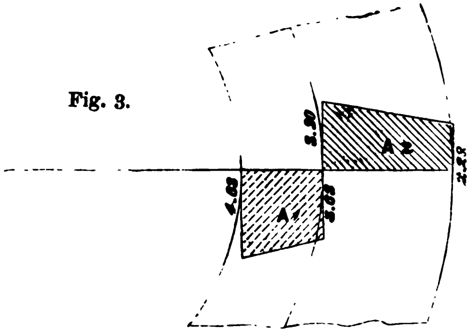


Fig. 4.

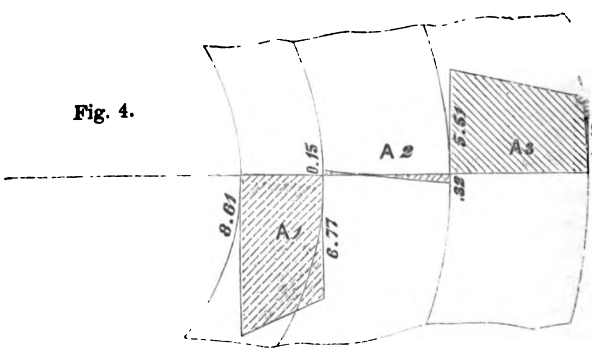
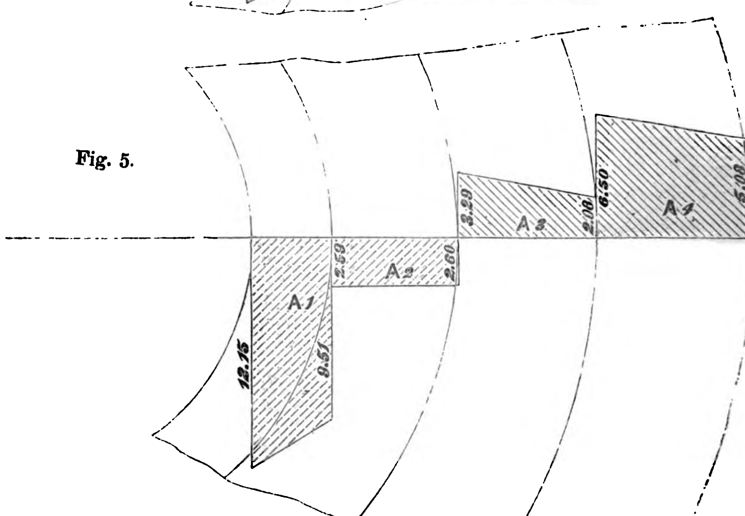


Fig. 5.



If, now, the gun is of any homogeneous material, such as cast iron, the state of tension at the time of explosion, and when the gun is about to burst, will be denoted by a curve H I, or H *i*, the former calculated according to Professor Hart, and the latter according to Professor Barlow's formula. Then, supposing the tensile force of the material to be 12 tons per square inch, and the thickness of the gun $6\frac{1}{2}$ inches, when the strain at G is G H, or 12 tons, at F it is F I = 3 tons, or F *i* = $1\frac{3}{4}$ ton, according as the one, or the other formula is adopted. The areas of these curves give, of course, the total strengths of the gun at the bursting point, and are found to be 36·72 tons and 30·871 tons respectively, instead of 78 tons, which it would have been if uniformly strained at 12 tons per square inch.

Now the object sought to be attained, in the method of construction under consideration, is, that each particle such as K, shall, when explosion takes place, be equally strained with G. In order that this may be so, the initial state of the tension must be such as is represented by the curve L N M, those between G and N being in compression, while those between N and M are in tension.

If, now, it is attempted to accomplish this by means of hoops, it will be found impossible, inasmuch as each hoop is a homogeneous cylinder, and follows the same law throughout its thickness, as is represented by the curve H I.

Figs. 3, 4, and 5, (page 298,) represent the successive states of stress of our rings, put on so as that when the explosion takes place, they shall be all equally strained at their inner circumferences.

Fig. 3 shows two rings.
4 „ three „
5 „ four „

The figures denote the strains, in tons per square inch.

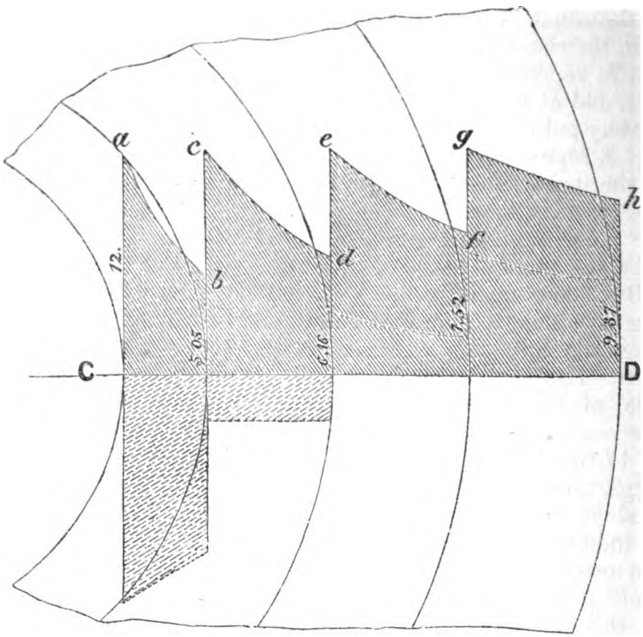
From this it will be seen, that when the four rings are put on, instead of the curve L N M of Fig. 2, there are a series of abrupt changes, the two inner rings being in compression and the two outer in tension.

When the explosion takes place, the state of maximum strain is represented by the next diagram, Fig. 6, (page 300).

The area between the dotted and the full lines, shows the work done by the explosion, and taking the total thickness of the gun, it amounts to 10·1 tons per inch of thickness; whereas, had the construction been of very thin rings, or of small wire, it would have been represented by the area between the dotted line L N M O H, (Fig. 2, page 297,) and would have been = 12 tons per inch of thickness, showing a superiority of about 20 per cent. in favour of the wire, over the hoops.

This is upon the supposition, that the workmanship of the hoops is perfect, which in practice cannot be attained. To afford some

Fig. 6.



idea of the accuracy required, the radii of the several rings, shown in the above diagram, are given in the following Table :—

No. of Ring.	Inner Radius.	Outer Radius.	Thickness.	Differences.
1	4·0000	5·3222	1·3222	$R_1 - \rho_2 =$ ·0031
2	5·3191	7·2928	1·9737	$R_2 - \rho_3 =$ ·0035
3	7·2893	9·4633	2·1740	$R_3 - \rho_4 =$ ·0035
4	9·4598	11·8247	2·3649	

Thus, it appears, that in order to give the requisite amount of initial stress, the external radius of the first ring must be $\frac{31}{10000}$ths of an inch, or about $\frac{1}{300}$th of an inch larger than the internal radius of the second: the external radii of the second and third $\frac{35}{10000}$ths of an inch greater than the internal radii of the rings next to them. Therefore, whilst the whole effect depends upon so small a quantity as about $\frac{1}{300}$th of an inch, it is evident, that a very small error in workmanship will materially affect the result,

and may tend to the most serious deviations from the proper initial strains.

This is a point of so much importance, that the Author has prepared the following diagrams, (Figs. 7 and 8, page 302,) to show the result of an error in workmanship, of $\frac{1}{500}$th part of an inch, in the size of the outer ring.

Fig. 7, represents the states of stress of the rings before explosion, and at the instant of maximum strain, when the rings are accurately put on.

Fig. 8, represents the states of stress of the same gun, when the outer ring has been made $\frac{1}{500}$th of an inch too small.

The result is, that before explosion, the maximum compression of the inner ring is increased from 10·086 tons to 11·244 tons, and the maximum tension of the outer ring from 5·778 tons to 7·823 tons per square inch; whilst at the time of maximum strain, during explosion, the tension of the same ring is only 2·268 tons, although the outer ring is strained to 12 tons, its assumed ultimate strength. The absolute strength of the gun is thus reduced from an average of 10·5 tons to 6 tons per inch of thickness, or about 40 per cent., by an error of only $\frac{1}{500}$th of an inch, in a ring of about 17 inches in diameter.

Rings, therefore, present practical difficulties, which are entirely avoided by the use of wire, as it may be coiled on with the exact strain indicated by theory.

The method adopted by the Author, was to coil a quantity of wire on a drum, fixed with its axis parallel to that of a lathe on which the gun was placed. On the axis of this drum, there was another drum, to which was applied a break, similar in principle to Prony's dynamometric break, so adjusted, as to give the exact tension required for each successive coil of the wire. The whole apparatus was extremely simple, and the wire was laid on with great regularity. Indeed it is evident, the apparatus might be so arranged, as that the process would proceed with the same ease and regularity, as winding thread on to a bobbin, and at the same time, with the greatest accuracy as regards the initial tension.

No such facility attends the use of hoops. They must be accurately bored, and after each layer is put on, the gun must be placed in the lathe, and the hoops be turned on the outside. Great accuracy of workmanship is indispensable; and not only is the amount of labour much greater, but it must be of a far higher, and consequently, of a more expensive class.

Then, as to accuracy of tension with hoops. The Author looks upon its attainment as almost impracticable. He is convinced, that the process of shrinking on is not to be depended upon. Not only is there a difficulty in insuring the exact temperature re-

Fig. 7.

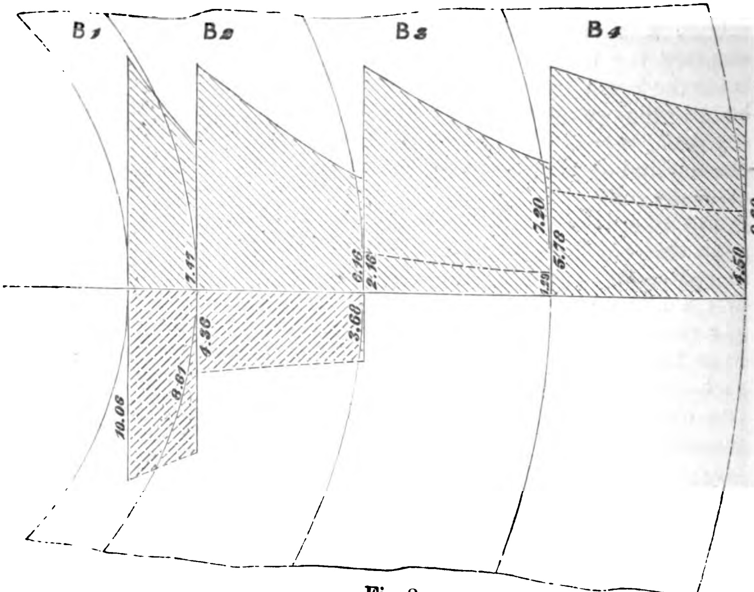
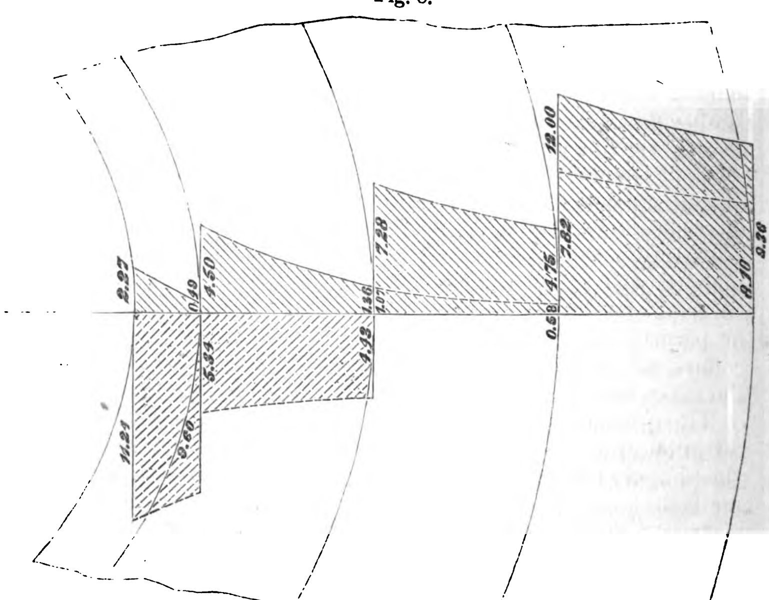


Fig. 8.



The dotted lines denote the state before, and the full lines after, explosion.

quired, but scarcely any two pieces of iron will shrink identically, and when the $\frac{1}{500}$th part of an inch of contraction would give rise to a great variation in tension, the necessity of perfect accuracy is apparent. But, it has been proposed, and the Author believes it is now solely advocated by Captain Blakely, that the hoops shall be forced, by hydrostatic pressure, on to a gun slightly conical, in longitudinal sections.[1] Here again occurs the practical difficulty of the attainment of extreme accuracy of workmanship, involving the highest class of skilled labour, and the greatest vigilance of supervision.

In the next place, hoops must always possess the defect of want of continuity of substance. However perfect the workmanship at first, the Author feels satisfied, that in large guns, the concussion of repeated firing would, ere long, shake them loose. Those who have had to do with heavy machinery, subject to violent jars, such as rolling mills, and forge hammers, well know how impossible it is to keep iron and iron, however well fitted, working together for any length of time, without shaking loose. The only remedy is to separate the pieces of iron from each other, by a packing of elastic material, so as to take off the jar. Now, the concussions in such machinery are insignificant, as compared with those in a large piece of ordnance, and, therefore, the use of hoops for large guns cannot prove satisfactory.

In the year 1854, Captain Blakely, R.A., laid this method of construction before the Ordnance authorities; but meeting with little encouragement, he took out a patent, in 1855, for a method of making guns. The specification of this patent, sealed 14th August, 1855, and dated 27th February, 1855, contains the following passage:—"I do not claim, as my invention, the method of forming guns, or cannon, by the application of collars, or rings heated, or shrunk upon a cylindrical inner tube, save and except, when the internal diameter of such collars, or rings, are, previously to being heated, so much smaller than the external diameter of the inner tube, on which they are shrunk, that after being cooled, the outer covering, formed by the rings, or collars, is in a state of tension, or permanent strain, similar to that produced, when the rings, or collars, are forced upon a conical surface, as before described, and the inner tube is, in both cases, similarly compressed."

This passage shows, that Captain Blakely clearly appreciated the advantages of the principle of construction which is the subject of this Paper, although seeking for practical results in a different method.

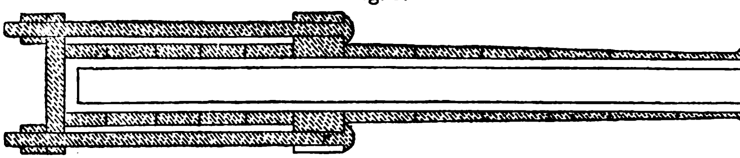
It is, however, due to Captain Blakely to record, that although

[1] In the course of the discussion, it appeared that this was the method now adopted by Mr. Whitworth.—AUTHOR.

he then looked chiefly to hoops, or collars, the idea of spirals, or rods of iron, or wire, was also present to his mind; for in a subsequent part of his specification, he distinctly refers to an outer covering of wire, or rods wound spirally in one, or more layers, for the purpose of strengthening old guns.

In an interesting lecture, delivered by Captain Blakely, at the United Service Institution, on the 21st of January, 1859, he gives an account of his experiments and endeavours to introduce this principle of construction to the notice of the Government authorities. In that lecture were recorded many very interesting facts and Captain Blakely's reasonings thereon; but it is to what was actually accomplished by Captain Blakely, that the Author wishes to direct attention.

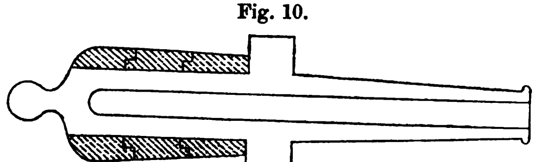
Fig. 9.



Captain Blakely's first gun was an 18-pounder, (Fig. 9,) consisting of one series of wrought-iron rings, shrunk on a cast-iron cylinder, $5\frac{1}{2}$ inches in diameter inside, and $1\frac{3}{4}$ inch thick. The wrought-iron rings were from 2 inches thick downwards. The total thickness of the breech was $3\frac{3}{4}$ inches, that of the ordinary 18-pounder service gun being $5\frac{3}{4}$ inches. This gun was fired frequently and stood well. It was then bored out as a 24-pounder, but not being truly bored, the cast iron was reduced, on one side, to only $\frac{1}{2}$ inch thick. In this state, it sustained, without injury, several hours' firing, with charges varying from one shot and 4 lbs. of powder, to one shot, two wads, and 8 lbs. of powder. At the third round, with this latter charge, it burst. This gun had a thickness of only $2\frac{1}{2}$ inches round the charges, as compared with a service 24-pounder, of 6 inches in thickness.

Captain Blakely next got a 9-pounder turned down, from the trunnions to the breech, and on this part he put wrought-iron rings of such a size as to replace the metal removed. (Fig. 10.)

Fig. 10.



This gun was fired, round for round, with a cast-iron service gun of the same size and weight. The following Table gives the result:—

No. of Shot. Blakely.	Charge of Powder.	No. of Shot.	No. of Rounds Fired.		No. of Shot. Fired from Service Gun.
			Blakely's.	Service.	
	Lbs.				
4	8	2	2	2	4
86	3	1	86	86	86
26	4	1	26	26	26
5	5	1	5	5	5
10	5	2	5	5	10
636	6	2	318	110	Burst 220
3	6	3	1	..	..
4	6	4	1	..	..
5	6	5	1	..	..
6	6	6	1	..	..
7	6	7	1	..	..
8	6	8	1	..	..
9	6	9	1	..	..
1,580	6	10	158	..	..
2,389			607	234	351

Thus, it appears, that Captain Blakely's gun stood 607 rounds, and the government service gun only 234 rounds; the number of shot thrown being 2,389 and 351 respectively, or nearly as 7 to 1.

The subsequent experiments, made by Captain Blakely, are described in his lecture; but enough has been said to show, that he had gone a long way to prove, practically, the truth of the principle. He did not, however, succeed in convincing the Government officials, as may be gathered from his pamphlet, published in 1859. His calculations having been reported upon by Mr. Heather, a mathematician, the system was declared inapplicable to cannon, by the Ordnance Select Committee, in a letter from which the following paragraph is an extract:—

"I am directed by Mr. Monsell to acquaint you, that the Committee, taking into consideration the different expansive powers of wrought and cast iron, are of opinion that guns so constructed could never be considered safe, as they might burst at any time, and the splinters from them would be very dangerous, (as shown in the late experiments,) and the Committee do not therefore recommend further experiments to be made with guns of this description."

In spite, however, of the opinion thus expressed by the Committee, it must be admitted, that Captain Blakely deserves great credit, for the spirit and perseverance with which he has, at great cost to himself, attempted to introduce a decided improvement into the arm of the service to which he belongs.

It was, however, in entire ignorance of what others were doing, or had done, that the Author arrived at the conclusion, that the construction, by means of wire, offered the greatest probability of

success, and to that construction exclusively he devoted his attention. The first point to be settled was, the amount of initial strain to be put on each coil.

The formula adopted by the Author was one based upon Professor Barlow's investigation, above referred to, and was :—

$$t = \mathrm{T} \cdot \frac{x^2 - r^2}{x^2} \quad . \quad . \quad . \quad (1)$$

Since the publication of Mr. Mallet's book, the Author has become acquainted with Professor Hart's investigation, the formula obtained from which is, as given therein :—

$$t = \mathrm{T} \cdot \mathrm{R} \, \frac{x^2 - ry}{x\,(r + y)}.$$

This, in the case of small wire, is nearly :—

$$t = \frac{\mathrm{T\,R}}{x} \cdot \frac{x - r}{x + r}.$$

These, however, are general formulæ which require modification, according to the varying circumstances of each case, before they can be applied to practice.

Without entering upon any discussion of these formulæ, the Author proceeds to describe the results obtained from his own experiments on cylinders prepared according to formula (1).

The method of conducting them was as follows. A number of brass cylinders were prepared exactly of the same dimensions, viz. :—

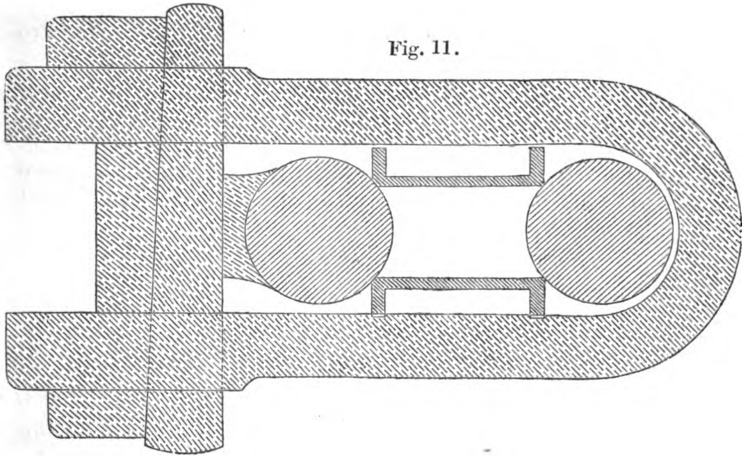
Internal diameter 1 inch.
External diameter $1\frac{3}{16}$ „
Thickness of brass $\frac{3}{32}$ „

These cylinders were accurately turned and bored, and had a flange $\frac{1}{4}$ inch in depth and $\frac{1}{8}$th inch in thickness, at each end. Each end was widened out, so as to afford seating to two gun-metal balls, which were accurately ground to fit them. The total content of each cylinder, with the balls in their places, was 300 grains of best sporting powder, which was alone used in this series of experiments. When the powder was put into the cylinder, and the balls were placed at each end, the whole was bound together by a very strong wrought-iron strap, similar to the strap of a connecting rod, with a jib and cotter. The cotter was driven tightly home, and the powder was then fired through a small touch-hole, left in the side of the seating. (Fig. 11.)

The first experiments were to ascertain the effect of the powder on the cylinders, without any wire. They were commenced with charges of powder, beginning at 50 grains, and increasing till the cylinder burst.

After this, cylinders with different thicknesses of iron wire, were tried in a similar manner.

Fig. 11.



The results are given in the following Table:—

EXPERIMENTS on BRASS CYLINDERS.

No. of Experiment.	No. of Cylinder.	Condition.	Charge of Powder.	Effect.
			Grains.	
1	1	Without wire . . .	50	Slightly bulged.
2	,,	Ditto	60	Bulged a little more.
3	,,	Ditto	70	Ditto external diameter $1\frac{5}{16}$.
4	,,	Ditto	80	Ditto ditto $1\frac{7}{16}$.
5	,,	Ditto	90	Burst.
6	2	2 coils of wire $\frac{1}{64}$ inch.	90	No effect.
7	,,	Ditto, one end loose .	100	Bulged at loose end.
8	3	Without wire . . .	70	Bulged to $1\frac{11}{32}$.
9	4	Six coils $\frac{1}{64}$ wire . .	100	No effect.
10	,,	Ditto	110	Ditto.
11	,,	Ditto	120	Ditto, one end of wire came loose.
12	,,	Same cylinder with one coil of $\frac{1}{32}$ wire . .	100	Burst—the end of the wire being badly fastened. Wire not injured.
13	5	Two coils of $\frac{1}{32}$ wire .	100	No effect.
14	,,	Ditto	120	Ditto
15	,,	Ditto	130	Ditto
16	6	Four coils of $\frac{1}{32}$ wire .	120	Ditto
17	,,	Ditto	130	Ditto
18	,,	Ditto	140	Ditto
19	,,	Ditto	150	Ditto
20	,,	Ditto	160	Ditto
21	,,	Ditto	170	Ditto
22	,,	Ditto	180	Ditto
23	,,	Ditto	200	Ditto

The strength of the wire used in these experiments was ascertained, by trial, to be as resisting a dead tension :—

$\frac{1}{64}$ wire	. .	23 lbs.	=	120,000 lbs. per square inch.
$\frac{1}{32}$ „	. .	70 „	=	92,000 „ „

If now, the expansive force of powder is taken to be inversely as the volume, its ultimate strength may be approximately arrived at from the last experiment. The powder then could not burst the cylinder. Now the strength of the cylinder, supposing all the material to be equally strained, could not exceed the following per lineal inch of cylinder :—

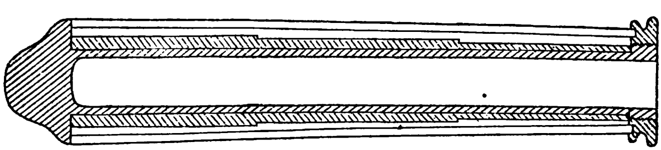
Wire	. . .	17,920 lbs.
Brass	. . .	3,136 „
		21,056 lbs., or 9·4 tons.

And as the internal diameter was exactly 1 inch, it shows, that the ultimate force of the material in Experiment 23, did not exceed 9·4 tons per square inch. Assuming the law, as above, the ultimate pressure, supposing the cylinder to have been full, could not exceed $9{\cdot}4 \times \frac{300}{200}$, or 13 tons per square inch.

The enormous strain, to which these cylinders were subjected, is evidenced by the effects upon the gun-metal balls, which were more, or less cut away by the gases, where they touched the cylinders.

These experiments, made on the 17th of May, 1855, were so satisfactory, that the Author proceeded to one on a larger scale. This consisted of a brass cylinder, of nearly the same internal dimensions as a 3-lb. mountain gun, say 3 inches in diameter, and about 36 inches long. The drawing of this cylinder has unfortunately been lost, but it is approximately represented in Fig. 12, from which it will be seen, that the thickness of the

Fig. 12.



brass was $\frac{1}{4}$ inch. At the breech end, it was covered with six coils of steel wire, square in section, and of No. 16 wire gauge, or $\frac{1}{16}$th of an inch. These coils extended about 15 inches along the cylinder, and were gradually reduced to two coils only, towards the muzzle. Consequently, the thickness of the cylinder was as follows :—

At the breech $\frac{1}{4}$ inch brass + $\frac{3}{8}$ inch iron = $\frac{5}{8}$ inch.
„ muzzle $\frac{1}{4}$ „ + $\frac{1}{8}$ „ = $\frac{3}{8}$ „

The thickness of the 3-pounder gun, with which it may be compared, being:—

At the breech . . . 2·37 inches.
„ muzzle . . . 0·75 „

It will be seen, that this cylinder was not mounted as a gun. It had no trunnions. It was cleaded with wood; and the object of the deep steel ring, which was screwed on the muzzle, was simply to cover the ends of the cleading. The cleading had nothing to do with the principle involved, and was only used to screen the construction from general observation.

This cylinder was proved, with repeated charges, varying from $\frac{1}{2}$ lb. of powder and one round shot, to $1\frac{1}{2}$ lb. of powder and two shots. The cylinder was simply laid on the ground with a slight elevation, its breech abutting against a massive stone wall, so as to prevent recoil. It stood the proof without injury, and the Author, on the 19th of June, 1855, addressed a letter to Lord Panmure, then Secretary of War, describing the experiments and the results, and offering the invention to the country.

As was then the fashion, he was referred to the Select Committee, and on 5th of July, 1855, he had an interview with that body, when he explained his views, and exhibited the small brass cylinders as well as the larger one last referred to, which he left, with the request that it might be proved, first as a 3-pounder gun, and then by gradually increasing charges up to bursting.

He remained in London, for some time, hoping to be present at these trials; but other matters called him away, and it was not till the 28th of July, 1855, that the trials were made. Unfortunately as it happened, the Author was unable to be present. The next official communication was a letter from the Ordnance Office, dated the 17th of September, containing a copy of the Report of the Select Committee in the following terms:—

"On the 28th of July a trial was made with Mr. Longridge's gun. The gun was clamped on a block of oak with iron clamps, and allowed to recoil on a wooden platform. Two rounds were fired, the first with a charge of 1-lb. powder, 1 shot, (fixed to wood bottom,) and one wood over the shot: the recoil was 7 feet; the gun was found to have slightly shifted its position on the block; a trifling expansion of the wire had also taken place at the breech.

"At the second round the gun was fired with 2 lbs. of powder, 1 shot, and 1 wad, and burst: the separation took place about 2 inches in front of the base ring; the breech was completely separated from the rest of the gun, and was blown 90 yards directly to the rear. The wire was unravelled to the length of

3 or 4 feet, the brass cylinder burst in a peculiar manner, turning its ends upwards and outwards. It also opened slightly at the centre of the gun; but the wire did not give way at that point.

"The ordinary proof charge for a gun of this diameter would be $1\frac{1}{4}$ lb., 1 shot, and 1 wad.

"In order to try more particularly the effect of the wire in giving strength to the cylinder, this gun was, after bursting, sawn in two at the centre, and one end of each portion was plugged with a brass plug, which was secured in its place by iron bands and several coils of wire: these guns were then secured to slides of wood as in the former instance; they were placed opposite the proof butt, and that made from the breech end was loaded with $\frac{1}{2}$ lb. powder and shot. It burst, the breech being blown out and the wire uncoiling to a considerable extent.

"The muzzle portion was then loaded with a similar charge; it did not burst, but was much shaken by the discharge, and portions of the iron bands gave way. It was then loaded with a charge of 1 lb. of powder and 1 shot, which on discharge burst in two places, the breech being completely separated from the gun and the slide on which it had been fired was rent into several pieces."

Previous to the receipt of the official communication, the Author had, through the courtesy of one of the members of the Committee, been informed of the result obtained. Feeling satisfied that the failure of the cylinder was due to some unexplained cause, he wrote to Lieut. Colonel Eardley Wilmot, begging for some further information, and particularly with respect to the method adopted for firing the gun, during the trials. Colonel Wilmot kindly lost no time in forwarding a sketch, showing the method of mounting, and this sketch at once explained the whole affair. The cylinder had, in fact, not burst at all, but had been torn asunder by the recoil. Fig. 13, which is taken from Colonel Wilmot's sketch, shows how this occurred.

The deep projecting steel flange, at the muzzle, was in fact the *point d'appui*, and the only thing that surprised the Author was, not that it failed at the second trial, but that it stood the first.

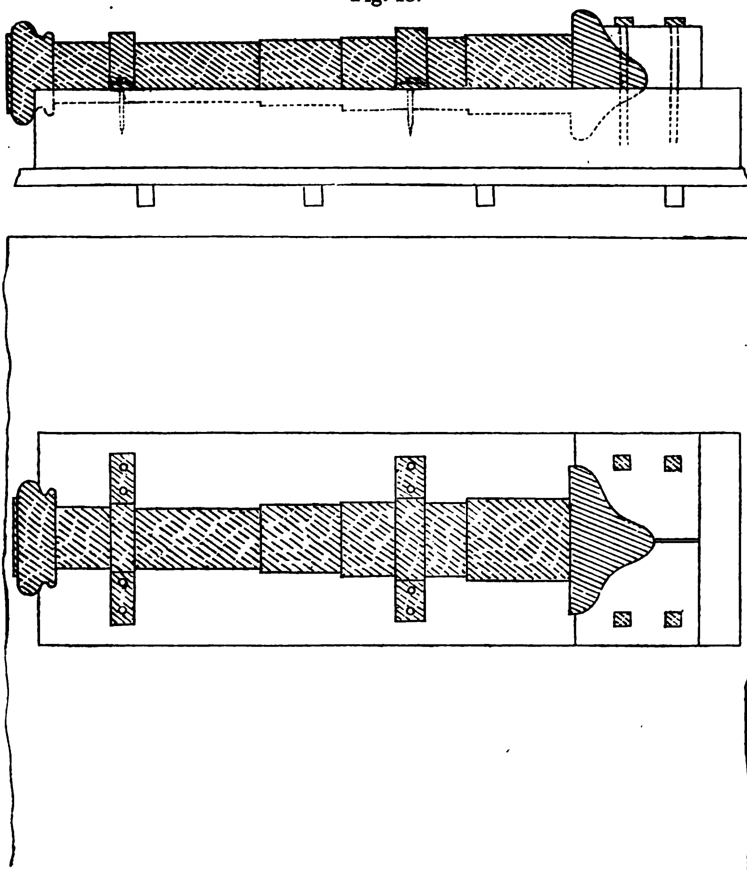
The subsequent burstings, as they are termed in the above Report, were not burstings, but the plugs put into the ends as breechings were simply blown out.

The fragments of the cylinder were, afterwards, forwarded to the Author. Upon examination he found, that the metal was much honeycombed at the breech, where it gave way, and by bad boring had been reduced below $\frac{3}{16}$ths of an inch in thickness on one side.

The Author, immediately after receiving the sketch, wrote again to Colonel Wilmot, pointing out the cause of failure. To this communication he received a reply stating, that Colonel Wilmot

believed, it was generally thought, that the experiment did not go to disprove the leading idea of his proposition, but that, on the contrary, the blowing out of the breech was an argument in favour of the barrel.

Fig. 13.



On the 21st of September, 1855, the Author again addiessed the Ordnance Office, pointing out the cause of failure of the above experiment, and offering to construct a larger gun on the same principle.

In answer to this he received a reply on the 27th of September, 1855, the substance of which was contained in the following words:—"I am directed to inform you, that no further trial of your invention can be made at the public expense."

With, perhaps, some degree of obstinacy, the Author once more wrote to the War Department, repeating his reasons for desiring

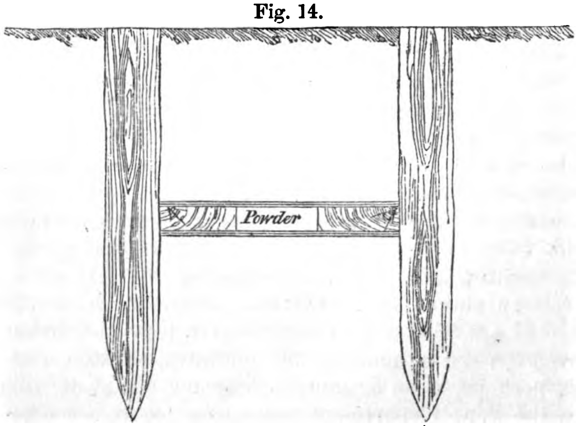
another trial, and pointing out, that what had been done, had been at his expense, and not at that of the public. In answer to this he was informed, that the question was again referred to the Select Committee. Finally, he received a letter from the War Department, dated 25th of October, 1855, to the following effect:—"I have the command of the Secretary of State for War to inform you, that the Committee having referred to the details of an experiment made with it [*i. e.* the Author's invention], consider, that no further trial is necessary, with a gun of this construction."

Thus ended the Author's dealings with the War Department. The result was not encouraging, as regarded the prospect of getting the invention tried by the Government; but the Author had seen no reason to doubt the correctness of the principle. Other affairs imperatively claimed his attention, and the matter lay dormant, as far as he was concerned, for some months, when he commenced a new series of experiments.

Before describing them, he will, however, complete the history of the brass cylinder tried at Woolwich.

Having obtained possession of the fragments, he took a piece of the cylinder, about 2 feet long, and stripped off the wire, with the exception of two coils. It was then a brass tube 2 feet long and $\frac{1}{4}$ inch thick, with two coils of square steel wire, each $\frac{1}{16}$th inch thick, making together $\frac{1}{4}$ inch of brass, and $\frac{1}{8}$th inch of wire. In the middle of this, he put $1\frac{1}{2}$ lb. of Government cannon powder, and the ends were filled up with close fitting wood plugs, fixed tightly with iron wedges. A trench 3 feet deep was then dug in stiff clay, and the cylinder was laid at the bottom. At each end a railway sleeper was driven firmly into the clay, and the trench was then filled in with clay, well pounded with a heavy beater. (Fig. 14.) The powder was then fired by means of a patent fuze.

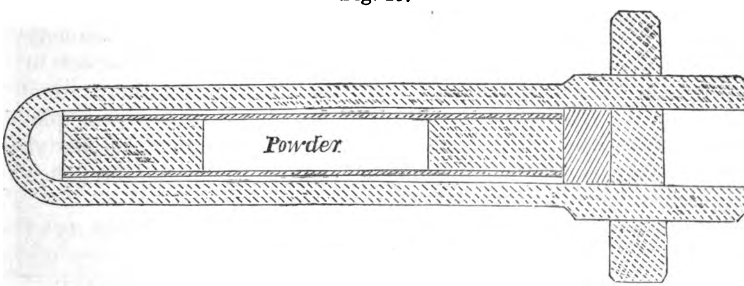
Fig. 14.



The wood plugs and sleepers were thrown out with great violence, and a large mass of clay at each end was blown out, but the cylinder was uninjured.

Determined, if possible, to burst it, the Author next put in 2 lbs. of powder, filled up the ends with close-fitting iron plugs, and bound the whole together with an iron strap, of a sectional area of 5 square inches, as shown in Fig. 15.

Fig. 15.



The powder was then fired, and the iron strap was torn asunder, but the cylinder was uninjured, except at the ends, where from the wire being imperfectly fastened, it uncoiled, and the cylinder was torn open. If the tensile force of the iron strap is taken at 18 tons per square inch, the force of the powder must have been above 13 tons per square inch, and yet this was resisted by $\frac{1}{4}$ inch of brass and $\frac{1}{8}$ inch of steel wire. The diametral strain must have been 39 tons, and taking the brass at 10 tons per square inch, it leaves 34 tons for the steel wire, which divided over the two sides, or $\frac{1}{4}$ inch, would give for the ultimate resisting strength of the wire so employed, not less than 136 tons per square inch of section. This wire, it should be observed, was of the finest quality.

The Author will now proceed to give an account of the second series of experiments made by him in March, 1856.

Many of those to whom he had described the experiments above recorded, whilst admitting the great increase of strength obtained, were yet of opinion, that it would be only practicable to apply the wire, in combination with a metal of a soft yielding nature, such as yellow brass, or pure copper. It was maintained, that it would be impossible to use the wire in combination with cast iron, owing to the assumed brittleness of that material, and it was objected, that the soft brass, or copper, would soon be worn out by the action of the shot, and the guns be rendered useless.

The Author's views were different. He looked on the inner shell simply as a means of confining the gases, and of transmitting the internal pressure to the wire; and knowing that cast iron would resist a crushing force of 40 tons, he was not afraid of subjecting

it to a strain in a normal direction, which, at the outside, could not exceed the strength of powder, or 17 tons per square inch. But he was quite aware, that no reasoning would suffice. Therefore, in his second series of experiments, which are about to be described, he resolved to use cast iron alone, in its hardest form,—as produced in a thin casting.

Two sets of cylinders were prepared. One set was intended to try the effect of wire, in enabling hard cast iron to resist a bursting strain; the other set, with a view of ascertaining whether it was possible to transmit the force of the powder, through a thin breech of cast iron, to a yielding substance, placed between that breech and the carriage of the gun. The view, taken by the Author, of recoil and its effects, was this. Action and reaction being equal and contrary, it is evident, that the recoil of the gun must increase, when the velocity, or weight of the ball is increased, and the distance of recoil must also increase, if the weight of the gun is diminished. If, therefore, the Author should succeed in throwing a 9-lb. shot, with a gun of the size of a three-pounder, some means must be devised, of providing for the increased recoil. There were two ways of meeting this. The first was by such a disposition of the material of the gun, as would absorb the blow, with the least possible strain upon the gun carriage, and the least internal stress on the gun itself. The recoil is due to a pressure, which begins at the moment of ignition of the powder, increases very rapidly and again decreases, as the ball moves along the chase of the gun. This pressure is, however, so rapid in its generation, that, practically, it is almost like the blow of a hammer. But it is still a pressure of short duration and great intensity, and its tendency is to tear a gun asunder, between the breech and the trunnions, to tear off the trunnions, or to fracture the carriage, and finally, to tear asunder the part of the gun beyond the trunnions, by its own inertia. Thus, in fact, the whole of the recoil induces a tensile force on the chase of the gun.

Now it is well known, that if it is desired to absorb the force of a blow, it is best effected, by interposing a heavy deep mass behind it, and therefore, the Author proposed to concentrate the weight of his gun, as much as possible, behind the breech.

The blow, thus coming, in the first instance, on a heavy mass of metal, would, to a great extent, diminish the jar upon the carriage. Again, the effect of any concussion is greatly diminished, by a yielding material placed between the body striking and the body struck. As it might be desirable, for practical reasons, to separate the gun itself from the mass of material intended to absorb the recoil, the Author wished to ascertain how far it was practicable to transmit the force through a thin breech, or diaphragm of a hard brittle substance, like cast iron, to a soft

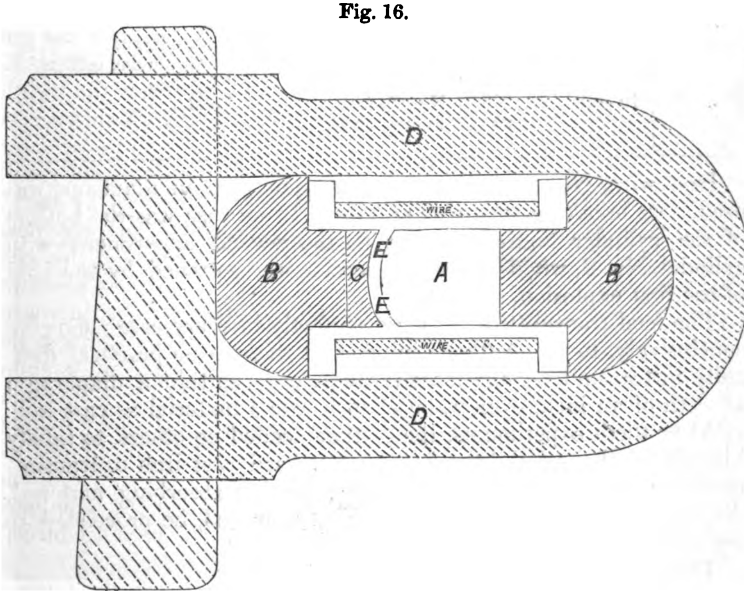
yielding material, like lead, and through it to the absorbing mass behind the breech. He did not expect to diminish the amount of recoil, materially, but to avoid those vibrations, which are so destructive between two hard metals in contact, and which always shake loose any system of bolting, or riveting, however perfect originally.

It was, with this view, that two distinct sets of cast-iron cylinders were prepared.

The first set was intended to try the possibility of transmitting pressure, as just stated, through a thin diaphragm.

The cylinders were of the dimensions shown in Fig. 16, in which

Fig. 16.



A is the powder chamber;

B and B, cast-iron plugs;

C, the space between the bottom of the powder chamber, and the plug B, filled up with a soft material;

D, a wrought-iron strap, with jib and cotter, for keying up the plugs B and B.

The object was to ascertain, whether the diaphragm at E E, would be shattered by the force of the explosion. Six cylinders were thus prepared, and loaded, and fired with charges, varying from 50 grains to 250 grains of Government cannon powder, the total contents of the cylinders being 310 grains.

The following Table gives the results:—

Cylinder.	Wire.	Charge.	Results.	Material behind the diaphragm.
		Grains.		
No. 0	2 coils	50	No effect.	Lead.
		50	Ditto.	"
		100	Ditto.	"
		120	Ditto.	"
		150	Burst.	"
" 1	4 coils	150	No effect.	"
		180	Top flange burst.	"
" 3	6 coils	180	No effect.	"
		200	Ditto.	"
		220	Ditto.	"
		240	Flange burst.	"
" 6	8 coils	240	Ditto.	"
" 8	8 coils	200	No effect.	Gutta-percha.
		220	Burst.	Gutta-percha, softened by heat.
" 9	10 coils	240	No effect.	Lead.
		250	Flange burst.	

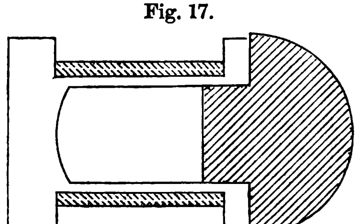
Iron wire, No. 21 wire gauge, or $\frac{1}{28}$th inch in diameter, was used. Its breaking strain was 60 lbs. In no case was the bottom of the cylinder injured, except in the second experiment with cylinder No. 8, when the gutta-percha was softened by the heat of the first explosion.

The lead transmitted the force perfectly in every case; showing conclusively, to the Author's mind, that there is no practical difficulty in transmitting the force through even so thin a diaphragm as $\frac{1}{10}$th of an inch, even when of so brittle a material as cast iron.

After these experiments, the Author needed no others, to satisfy himself of the suitability of even very hard cast iron to transmit the force of gunpowder to wire, or any other absorbing material. As, however, other cylinders had been prepared, he proceeded to try their strength.

These cylinders are shown in Fig. 17.

Fig. 17.



They each contained 305 grains, when full to the plug. The plugs were made to fit accurately, and the powder was fired through a small vent, or touch hole, not larger than a small pin.

The following Table gives the results :—

No. of Cylr.	Wire.	Charge.	Results.	Remarks.
		Grains.		
No. 0	None	40	No effect.	
	Ditto	50	Ditto.	
	Ditto	60	Ditto.	
	Ditto	70	Ditto.	
	Ditto	80	Burst.	
„ 2	4 coils	130	No effect.	
	,,	150	Flange burst.	
„ 7	8 coils	200	No effect.	A wrought-iron flange, ¼ inch deep, contracted on flange.
	,,	220	Ditto.	
	,,	240	Ditto.	
	,,	250	Ditto.	
	,,	260	Ditto.	
	,,	270	Ditto.	
	,,	280	Ditto.	
	,,	290	Ditto.	Hoop on flange shifted.
„ 5	8 coils	200	No effect.	
	,,	220	Ditto.	
	,,	230	Ditto.	
	,,	240	..	Flange cracked.
„ 4	4 coils	200	No effect.	
	,,	250	..	Flange cracked.
„ 10	10 coils	310	No effect.	

In these experiments iron wire, No. 21 wire gauge, or $\frac{1}{28}$th inch in diameter was used. Its breaking strain was 60 lbs.; consequently the actual strength of the material in the cylinder per lineal inch was :—

No. 0	Cast iron $0\cdot10 \times 2 \times$ tons = Nil.	$1\cdot76$ tons		$1\cdot76$ tons.
„ 2	Cast iron as above	$1\cdot76$ „		
	Wire $4 \times 28 \times 2 \times \frac{60}{2240}$	$6\cdot00$ „		$7\cdot76$ „
„ 7	Cast iron	$1\cdot76$ „		
	Wire $8 \times 28 \times 2 \times \frac{60}{2240}$	$12\cdot00$ „		$13\cdot76$ „
„ 5	Same as No. 7			$13\cdot76$ „
„ 4	Same as No. 2			$7\cdot76$ „
„ 10	Cast iron	$1\cdot76$ „		
	Wire $10 \times 28 \times 2 \times \frac{60}{2240}$	$15\cdot00$ „		$16\cdot76$ „

The enormous force of the expansive gases, in these experiments, was shown by their action on the plugs, which although accurately fitted and of hard iron, were chiselled and grooved out, in an extraordinary manner, as may be seen in one specimen exhibited. The vents, too, were rapidly enlarged.

The results, as regards strength, were so conclusive, that the Author proceeded to construct a small gun, (Fig. 18). This gun

was 2·96 inches in bore and 36 inches long in the clear; it had on it twelve coils of No. 16 W. G. iron wire, at the breech, decreasing to four coils at the muzzle. The thickness of cast iron was $\frac{11}{16}$ths of an inch at the breech and $\frac{1}{2}$ inch at the muzzle.

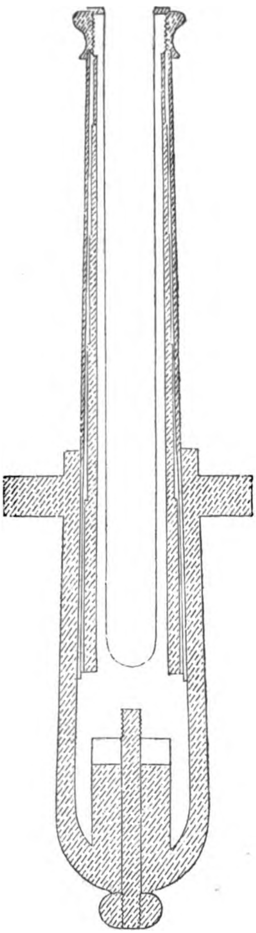


Fig. 18.

The gun was cast hollow, and a recess was left in the thick part of the breech, in which an india-rubber washer, $\frac{3}{4}$ inch thick, was placed. The trunnions formed no part of the gun, but consisted of a strap passing round the breech, with two side rods, extending about one-third of the length of the gun, and terminating in the trunnions themselves. Thus, the whole force of the recoil was transmitted through the heavy mass at the breech, then through the india-rubber, and along the side rods to the trunnions.

The whole was then mounted on a wood carriage, on four roller wheels, about 8 inches diameter.

The weight of the gun and wrought-iron trunnion strap was 3 cwt., and the carriage 2 cwt. 0 qr. 15 lbs., making a total of 5 cwt. 0 qr. 15 lbs.

The shot were cast as nearly the size of the bore as possible, so as to move freely, but with very little windage. The spherical shot weighed $3\frac{5}{8}$ lbs., and the conical shot from 6 lbs. to $7\frac{1}{2}$ lbs.

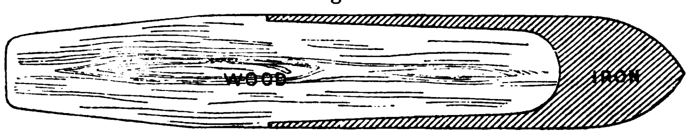
The following are the results with 7° elevation, the powder used being Government cannon powder.

Firing on Cambois Sands, 4th June, 1856.

No.	Description of Shot.	Weight.		Charge of Powder.	Range to First Graze.
		lbs.		oz.	
9	Round . .	$3\frac{5}{8}$	7°	11	1,400 yards.
4	Elongated .	$6\frac{1}{2}$	7°	11	1,200 yards.
5	Ditto . .	6	7°	8	1,220 yards.
6	Ditto . .	$7\frac{1}{2}$	7°	11	1,542 yards.
8	Ditto . .	7	7°	11	Lost beyond 1,500 yards.
7	Ditto . .	7	7°	16	Lost beyond 1,800 yards.
10	Ditto . .	$6\frac{1}{2}$	7°	16	1,500 yards.
11	Ditto . .	$6\frac{1}{2}$	7°	16	Lost beyond 1,800 yards.

The variations in the range were due, partly, to not having any very exact means of adjusting the elevations, and partly to differences in the form of the shots. The trials, above recorded, were only intended as preliminary, it being the Author's intention to carry out a more complete series, at another time. Unfortunately this intention was frustrated by an accident, which destroyed the gun, and which the Author now proceeds to describe. He had an idea, that it might be possible to obtain more accuracy of flight by using a shot somewhat on the principle of an arrow, viz., with a long light shaft and heavy head. This shot is shown in Fig. 19. The head was of cast-iron, and weighed about 8½ lbs.

Fig. 19.



The shaft was of fir-wood, fitted tight into the iron head. When fired, by mistake, with a heavy charge of powder, the result was that the wood was driven forward with great force, entering and splitting the iron head. This wedged it so tightly in the chase, that it never left the gun, but tore it asunder about 12 inches from the muzzle; the muzzle and the shot in it were thrown about 15 yards forward, and the wire was uncoiled, but not broken.

This accident, it will be easily seen, was due entirely to the action of the shot, and had nothing to do with the principle of construction of the gun.

Enough however had been done to show, that with a gun weighing only 3 cwt. a shot of 7½ lbs. could be thrown from 1,500 to 1,800 yards,—a result, it is believed, not attainable by any 6-pounder in the service.

So ended the Author's experiments on guns. He had neither time, nor money, at his disposal to carry them further; and although he was thus reluctantly compelled to relinquish the subject, he was fully impressed with the thorough soundness and practical facility of the system, and this in spite of its having been pronounced by the highest authority, unnecessary to make further experiments with a gun of this description.

Another application of the same principle is to the CONSTRUCTION of the CYLINDERS of HYDRAULIC PRESSES. When these are of large size, they are of great weight, and are very liable to be fractured.

Cylinders bound with wire may be made of any size, with the greatest facility, and at considerably less first cost than the unwieldy cylinders now in use.

Taking, for example, a cylinder for a 10-inch ram, with a stroke of 40 inches; the weight of it, when rough, is 46 cwt., and when finished, 31 cwt., and its cost when finished, is about £22.

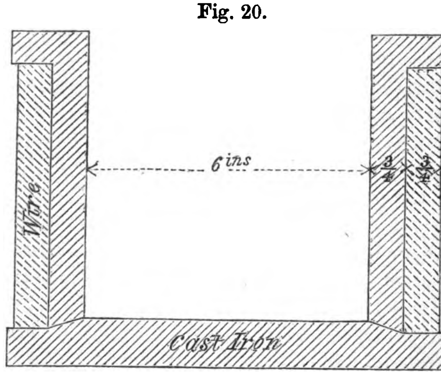
A wire-bound cylinder of the same strength would only weigh 7 cwt., and the cost would not exceed £10.

The difference in first cost, though considerable, is of less consequence than the decrease in the risk of failure, and the vastly increased portability of the wire-bound cylinders. This latter quality is of peculiar advantage in presses intended for exportation to India and to South America, where the means of transport are frequently quite inadequate to the carriage of heavy weights.

In discussing this question, with makers of hydraulic presses, the Author has generally been met with the objection, that the thinness of the cast iron would enable the pressure to force the water through. To try how far this was the case, he constructed a small cylinder, 6 inches in diameter, the metal of which was $\frac{3}{4}$ inch thick, and around it he put twelve coils of No. 16 iron wire, equal to a rim of $\frac{3}{4}$ inch.

This cylinder, represented by Fig. 20, was tested up to a

Fig. 20.



pressure of 6 tons per square inch, without any escape of water. At this pressure it gave way, by shearing the side walls off the bottom plate. The reason for this is obvious. The bottom plate prevented the side walls from expanding, which they were free to do where bound round with wire. The wire was not broken, nor were the side walls shattered.

There are, doubtless, many other useful applications of this principle; but it is to its value in the construction of artillery, that attention is chiefly sought to be directed. There are many questions involved in the construction of an efficient gun, or mortar,

besides that of the absolute strength. These questions have not escaped the Author's attention; and he believes, that the principle, now under consideration, affords very great facilities, and may be successfully carried into effect, for obtaining every desirable quality in destructive weapons of whatever description, whether for light field-artillery, such as breech-loading rifled guns, or even revolvers, or for heavy guns and mortars for land defences, or for siege purposes; and he would commence the construction of a 15-inch gun, or a 36-inch mortar, with the utmost confidence in the results. He is quite prepared to meet with objections, and though perhaps the old ones, viz., that these guns would be too light, that cast iron and wrought iron would never work together, that their different rates of expansion would destroy the gun, and so forth, may not now be persisted in, facts having answered them; still other difficulties may present themselves to the minds of those who have not fully studied the subject, or whose attention is now directed to it for the first time, and although the details of construction and arrangements, which are required to make an efficient weapon, scarcely come within the limits of this Paper, the Author will be glad to hear any objections which may appear to exist, and to reply to them to the best of his ability.

The Paper is illustrated by a series of diagrams, from which the woodcuts, (Figs. 1 to 26,) have been compiled.

[APPENDIX.

APPENDIX.

Anticipating the probability of the extension of the discussion beyond the subject of construction, the Author has prepared the two following Notes;—1°, on the strength of gunpowder; and, 2°, on the causes of deviation in projectiles, and the mode of counteracting the same by rifling. The mathematical investigations referred to in these Notes, as well as the investigation of the strength of hooped, or wired cylinders, by Mr. C. H. Brooks, are given in the latter portion of the Appendix; (page 329.)

1°. Force of Gunpowder.

In the foregoing Paper, the initial and ultimate force of gunpowder has been estimated, by the Author, at from 17 tons to 20 tons per square inch. Various authorities have, however, assumed that the force attained was nearly double the Author's estimate.

Unfortunately, no means exist of accurately determining that important datum, owing to the absence of any exact knowledge of the rate at which powder burns in a gun.

It, therefore, still appears to the Author, that the method he pursued is that which is most likely to give reliable results; viz., to construct vessels of certain known strengths, and by actual trial, to ascertain what thickness of metal will resist the full force of powder when no escape is permitted.

The indirect methods are as follows:—

1st. From a deduction of the actual volume of gas generated, and thence by an estimate of the force of the gas, when compressed into its original bulk, and at the same time subjected to the great elevation of temperature due to the combustion.

2nd. From experiments with the ballistic pendulum, whereby the velocity of the ball leaving the gun is ascertained, and from this velocity the initial force of the powder is estimated.

Both these methods fail, from the absence of correct data. In the former case, the temperature is not known, nor is the index which represents the relation between pressure and volume, when, instead of Mariotte's law, the true law is applied.

In Captain Boxer's "Treatise on Artillery,"[1] the permanent gases evolved from 1 cubic foot of gunpowder, when reduced to ordinary temperature, are stated to be:—

Nitrogen . . .	79·4	cubic feet.
Carbonic Acid . .	238·0	„
	317·4	„

This, if compressed into the bulk originally occupied by the powder, according to Mariotte's law, would give a pressure of 317·4 atmospheres.

To take in the effect of temperature, Captain Boxer estimates the temperature at 3,000° Fahrenheit; and assuming, that the expansion is $\frac{1}{480}$th of the volume for each degree of Fahrenheit, he brings the total expanded volume of gases to

$317 \cdot 4 \times \dfrac{3{,}000 - 60}{480} = 2{,}154$ feet; which, if compressed to the original volume of the powder, would give a pressure of 2,154 atmospheres, or 14·4 tons per square inch.

[1] *Vide* "Treatise on Artillery." 1854, p. 14.

The pressure may, however, be estimated by this law, represented by the equation to an adiabatic curve $p \propto \frac{1}{v_k}$, or $\frac{p}{p'} = \left(\frac{v'}{v}\right)^k$.

Here, p and p' are the pressures before and after compression, v and v' the corresponding volumes, and k the ratio of the specific heat at constant volume to that at constant pressure. In the case of air, $k = 1{\cdot}41$; and if this be the same for carbonic acid and nitrogen, (which, however, is rather uncertain), the pressure after compression would be $= 317{\cdot}4$.
$= 3{,}367$ atmospheres.
$= 22{\cdot}17$ tons per square inch.

In estimating the initial force of powder from the velocity as ascertained by the ballistic pendulum, the method adopted by Dr. Hutton, and followed by other artillerists, is to find the value of n in the formula :—

$$v = 47{\cdot}4\sqrt{\frac{n\,h\,d^2}{p+w}\,.\,\text{Log.}\frac{b}{a}}\text{; from which is obtained}$$

$$n = \frac{(p+w)\,v^2}{\overline{47{\cdot}4}|^2\,h\,d^2\,\text{Log.}\frac{b}{a}} \quad . \quad . \quad . \quad . \quad (1).$$

From this, Hutton found the value of n to be from 2,000 to 2,400 atmospheres, or from 13 tons to 16 tons per square inch.

The above formula is, however, based on two erroneous assumptions; first, that the variation of pressure is according to Mariotte's law; and secondly, that the whole of the powder is instantaneously converted into gas. The former assumption may be corrected by adopting the true thermo-dynamical law, and the formula then becomes :—

$$n = \frac{(p+w)\,v^2}{\overline{47.4}|^2\,d^2\,\frac{h^k\,(a^{1-k} - b^{1-k})}{k-1}} \quad . \quad . \quad (2).$$

Now in the case of Mr. Whitworth's 80-pounder gun, the velocity of the shot is stated to be 1,300 feet per second, with a charge of 12 lbs. of powder, occupying 20 inches of the barrel. Therefore :—

d = mean diameter of gun . = 5·25 inches.
b = length of gun . . . = 108 „
a = length of charge . . = 20 „
w = weight of shot . . . = 80 × 16 ounces.
p = half the weight of powder = 6 × 16 „
v = velocity of shot . . . = 1,300 feet per second.
h = length filled with powder = 19 inches.
k = 1·41 (?), as above.

Whence are obtained the following values of n :—

	Atmospheres.		Tons Pressure.
From (1) Hutton's formula, based on Mariotte's law . .	2,638	=	17·37
„ (2) Hutton's formula, based on the thermo-dynamic law	3,733	=	24·58

These latter results, though probably approaching the truth, must be taken with the limitation involved in the fact, that the burning of the powder is not instantaneous, but is really a work of time. If the relation between the time and the increase of pressure were known, the initial force of the powder, and the maximum strain on the gun, might be determined with greater accuracy.

It may, however, be shown, that the actual strain is always below that given by the formula (2), and that it is less, as the rate of combustion is slower.

It has lately been asserted by the Secretary at War, Mr. Sidney Herbert, (Speech on Army Estimates, 17th of February, 1860,) that "we have been wrong for some time in using powder of so quick a detonating nature for artillery purposes, and

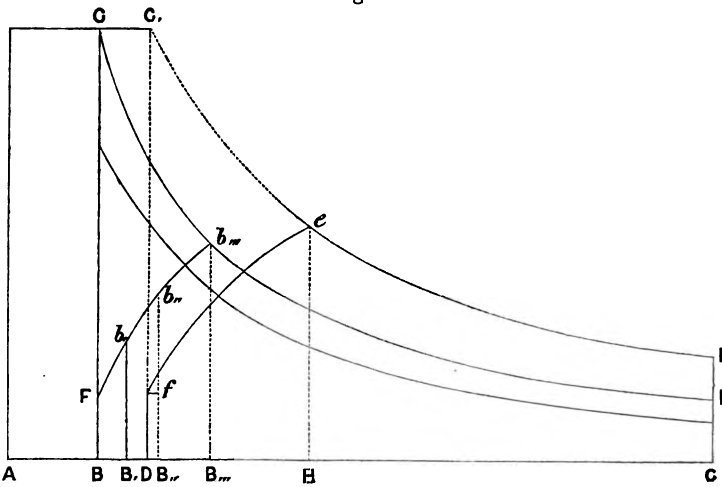
especially for rifled cannon, which require weaker and slower powder than that suited to other arms."

An assertion so extraordinary, coming from such a source, calls for careful examination.

This question may be briefly investigated in the following manner:—

In Fig. 21, let A B C be the chase of the gun, and A B the portion occupied by the powder before explosion. Now as soon as the powder begins to burn, the pressure

Fig. 21.



accumulates in A B, until it is equal to the resistance of the ball. Let this pressure be denoted by B F. The ball then begins to move towards C, and when it arrives at $B_{,}B_{,,}$ the pressure may be represented by the ordinates $B_{,}\,b_{,}\,B_{,,}\,b_{,,}$. Let the powder be all burnt when the ball arrives at $B_{,,,}$, and let the corresponding pressure be denoted by $B_{,,,}\,b_{,,,}$. Then the curve $F\,b_{,}\,b_{,,}\,b_{,,,}$ represents the curve of pressure, up to the point $B_{,,,}$. From this point to the end of the gun, the pressure will be represented by the ordinates of an adiabatic curve $b_{,,,}\,E$, and the total work done by the ball will be represented by the area $B\,F\,b_{,,,}\,E\,C\,B$. This is, of course, on the assumption, that there is no transmission of heat from the gases to the gun. Any such transmission would, of course, decrease the ordinates and the curve area; but the heat, so transmitted, is so small a proportion of the whole heat generated, that it may practically be neglected.

If now the adiabatic curve $E\,b_{,,,}$ be continued to G, B G would represent the initial pressure, if the powder had exploded instantaneously, and the area B G E C B the work done on the ball. It therefore appears, that the work actually done is less than the work of powder burning instantaneously, by the area $F\,b_{,,,}\,G\,F$.

If, then, B G E C B represents the work done, as determined by formula (2), it is obvious, that to produce the same effect with a slow-burning powder, more of it must be used. If the length of powder is represented by A D, a curve results such as $D\,f\,e\,E_{,}\,C\,D$, which must be equal in area to B G E C B, and the maximum pressure is represented by $H\,e$. Now $e\,E_{,}$ must be a portion of an adiabatic curve, descending from $G_{,}$, and $G_{,}\,D$ must be equal to G B, because each represents the same force, viz., the force of instantaneous explosion; consequently, $H\,e$ is always less than G B.

The result, therefore, is that with a slow-burning powder the strain on the gun is less, but the quantity of powder required is greater; and the necessity of a slow powder, adverted to by the Secretary at War, can only be caused by the

guns not being sufficiently strong to resist the more economical and more powerful quick-burning powder.

In concluding this Note, the Author would take the opportunity of expressing the hope, that a series of experiments may be instituted with rifled ordnance, and all the important appliances of the present day, somewhat similar to those conducted by Dr. Hutton. Such experiments, carefully conducted, could not fail to give results of great value to the science and practice of gunnery.

2°. Effect of Twist.

It is not proposed in this Note on the causes of deviation of projectiles, and the remedy by rifling, to do more than to make a few general remarks on the subject. They, however, appear to be called for by the great variety of opinions existing amongst the rifled-gun makers of the day. The following are the degrees of twist given in three cases:—

Mr. Haddan's	..	1 turn in	100	calibres.
Sir W. Armstrong's	..	1 „	38	„
Mr. Whitworth's	..	1 „	20	„

This great discrepancy in practice is very startling, and it may not be amiss to give some consideration to the subject.

The object of rifling being to diminish, as far as possible, the deviation from the line of aim attendant on ordinary shot, these should be first enumerated, and their causes be described.

They are as follows:—

1st. Action of the wind.
2nd. Rotation of the earth.
3rd. Want of symmetry of the shot around the longitudinal axis passing through the centre of gravity.
4th. Position of the centre of gravity before, or behind the centre of figure.
5th. Friction of the shot in the air.
6th. Want of horizontality of the axis of the trunnions.

The first two of these are incidental alike to all guns, and can only be dealt with by making allowances for their effects in practice; the third, fourth, and fifth are those with which rifling has to do.

If the material of the shot is not homogeneous, or its form is not symmetrical, the resistance of the air causes the projectile to deviate from the true line of flight. Again, if the centre of gravity is behind the centre of the figure, the shot will turn over. Lastly, if the shot leaves the gun with a rotation arising from striking, or rubbing against the inside of the chase, and is not determined by any specific direction, it will fly off to one side, or the other, according to the accidental circumstances under which it leaves the gun.

In Fig. 22, let A B be a shot projected in the direction of the arrow. Now, if the front end is not symmetrical, but is formed as shown at B C, it is evident, that the resistance of the air will cause the shot to deflect in the direction D E, (Fig. 23,) and that its path, as projected on a horizontal plane, would be a curve to the left of D G. If, however, the shot rotates on its axis, the extent of lateral deviation is limited, and the shot is brought back from E towards the axis D G. Now, it is generally stated and believed, that this retrograde motion goes on, until the shot reaches a point F, as far to the right

Fig. 22.

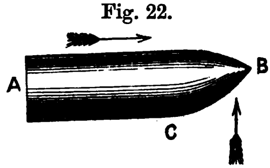
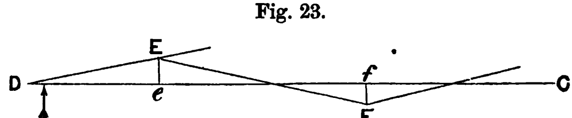


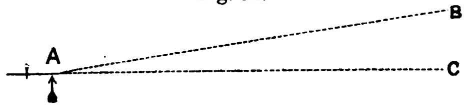
Fig. 23.



of D G as E was to the left, and that, in fact, the shot travels in a spiral around the axis D G, its greatest deviation, at any part of its path, being the distance

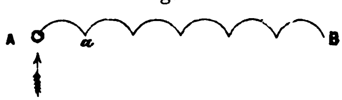
E *e*, or F *f*. This, however, is not the case. As is shown in the investigation by Mr. C. H. Brooks, (page 335,) the path of the projectile is of a much more complex form, and results in a deviation, increasing uniformly with the distance from the gun, and depending as to its direction, on the direction of the deflecting force, at the moment of its first application. If A be the gun, (Fig. 24,) seen projected on a horizontal plane, and the deflecting force acts on the shot as it leaves the muzzle, in a vertical direction downwards, the general

Fig. 24.



projection of the line of flight will be a line A B, deviating to the right, or to the left of A C, according as the twist is left, or right-handed. If the deflecting force acts in the opposite direction, the shot will be deflected to the right of A C, and whatever be the direction of the deflecting force at the first exit of the shot, the deviation will be a uniformly increasing one at right angles to it. But the line A B is not absolutely a straight line; it is a curve of double curvature, and if projected on a vertical plane at right angles to the axis A C, would consist of a series of cycloidal curves, (Fig. 25,) increasing the distance of the shot from A C, by the length A *a*, of one of these cycloidal curves at each revolution. The length of each of these cycloidal curves depends upon the amount of the deflecting force, and the number of them is equal to the number of revolutions made by the shot in its flight. The formula for calculating these curves will be found at page 336, and the following Table gives the results as calculated for the several guns therein mentioned, and the aggregate deviation from the line of axis of the gun, at a distance of 1,000 yards, and for a deflecting force, which would have given a deviation of 10 yards to a non-rifled shot, projected under the same circumstances :—

Fig. 25.



Name of Gun.	Amount of Twist.	Number of Turns in 1,000 yards.	Breadth of Cycloid.	Length of Cycloid.	Total Deviation in 1,000 yards.
Haddan .	1 in 50 ft.	60	$\frac{1}{90}$th of an inch	$\frac{1}{30}$th of an inch	2·0 inches
Armstrong	1 in 10 ft.	300	$\frac{1}{2250}$th of an inch	$\frac{1}{750}$th of an inch	0·4 inch
Whitworth	1 in 5 ft.	600	$\frac{1}{9000}$th of an inch	$\frac{1}{3000}$th of an inch	0·2 inch

The aggregate amount of deviation, even with the very slow twist of Mr. Haddan's gun, is very small, and this teaches, that as far as the correction of the deviation, due to want of symmetry, is concerned, the more rapid twists of Mr. Whitworth's and Sir W. Armstrong's are unnecessary.

It is, however, necessary that the rotative momentum be sufficient to keep up the spinning motion to the end of the flight of the shot, and this may require a greater degree of twist, than would be required simply for the purpose of correcting the deviation due to the deflecting force. Experiments are wanting, to show the decrease of rotation due to the friction of the projectile in the air. In Mr. Haddan's projectile, with an initial velocity of 1,300 feet per second, the number of revolutions would be twenty-six per second; and it does not appear likely, that this would be much reduced in the few seconds of the projectile's

flight, even to its most distant range. Therefore, in this respect also, the rapid twist adopted by Mr. Whitworth and Sir W. Armstrong appears unnecessary.

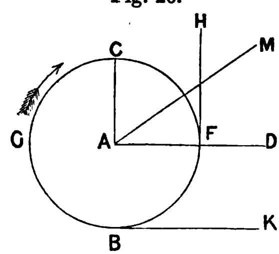
The next point for consideration, is the influence of the position of the centre of gravity before, or behind the centre of figure of the shot. The gyroscope affords an excellent means of illustrating this. If a weight is attached to the axis of this instrument, when in rotation, the axis will deviate in the same direction as the rotation, if the weight is behind the revolving disc, and *vice versâ.*

The velocity of this horizontal deviation of the axis is smaller, as the rotative velocity is greater. If, then, in a rifled shot, the centre of gravity is behind the centre of the figure, the shot will deviate to the right, with a right-handed twist. If, on the other hand, the centre of gravity is forward, the deviation will be to the left; and these deviations will be greater, as the velocity of rotation is less; that is to say, as the twist is slower. Here, then, the advantages of a rapid twist is manifest, but it must be borne in mind, that the deviation here sought to be counteracted is solely due to the centre of gravity being placed before, or behind the centre of the figure; and if these centres coincide, no tendency to deviate exists.

The fifth cause of deviation is from the friction of the shot against the air.

If a body is revolving rapidly in any fluid pressing equally against it in every direction, it is obvious, that the only effect of the fluid is to diminish, and finally, to destroy the velocity, without changing the position of the axis A, (Fig. 26). But if the fluid presses with a greater force on the side B, for instance, than on C, the axis will move in the direction D. Again, if the velocity of motion is greater at F than at G, the tendency is to move the axis in the direction A C.

Fig. 26.



Now in the case of an elongated rifled shot, both these actions take place. The pressure of the air is always greatest on the under side, and consequently, the axis is moved in the direction of the twist. Moreover, the side F is always meeting the air, with the velocity due to the sum of the velocity of rotation and the falling velocity of the shot; whereas the opposite side is meeting the air, with the velocity due to the difference of these two; consequently, the effect is to roll the shot upwards, in the direction F H, and sideways in the direction B K; the actual result being a deviation in some intermediate direction A M.

This deviation, which is unavoidable in all rifled shot, is greater as the twist is greater, and may possibly vary as the square of the velocity of rotation, *i. e.*, as the square of the rate of twist.

It will probably, also, be a good deal affected by the nature of the rifling, being, of course, greatest with a rough rifled surface.

The deviation due to the friction, as last described, is always in the direction of the twist. It may, therefore, be, to some extent, counteracted by the gyroscopic deviation of the centre of gravity, if the shot is placed in advance of the centre of the figure. This gives a deviation to the side opposite to the direction of twist, so that the actual deviation is, in one case, the sum, and in the other, the difference of the two deviations.

The sixth source of deviation is due to the want of horizontality of the axis of the trunnions.

The sights being vertical, when the trunnions are horizontal, it is evident, that if the axis of the trunnions is placed at an angle with the horizon, the line of sights will no longer coincide with the axis of the gun, when the gun is laid at any elevation.

If α be the error in azimuth, arising from this cause;
ϵ the angle of inclination of the trunnions with the horizon;
θ the elevation of the gun;

Then it is shown, at page 336, that

$$\text{tang. } \alpha = \sin. \theta . \text{ tang. } \epsilon :$$

from which it is easy to calculate the deviation in any given range.

The following Table shows the amount of lateral deviation, due to the axis of the trunnions being 1° out of the horizontal line :—

Angle of Elevation.	Azimuthal Error.	Range of Shot.	Lateral Deviation.
35°	42′	8,800 yards	110 yards
10°	$10\frac{1}{2}$′	4,000 „	12 „
5°	5′	2,300 „	$3\frac{1}{2}$ „

When it is considered, how difficult it is to detect, by the eye, so small a deviation from the horizon as 1°, it is evident, that for accurate practice some means must be adopted for accurately levelling the axis of the trunnions.

There may be other causes of deviation, than those above enumerated, but so far as the above investigation goes, it tends to show, that a very moderate amount of twist is all that is generally required, and that the only necessity of increasing the twist arises from the position of the centre of gravity of the shot being such as to make the gyroscopic deviation considerable.

It remains to be considered, what is the amount of force required to impart a certain rotative velocity, and what is the consequent strain on the gun.

Let P = force required at the circumference of the shot.
r = radius of shot.
ρ = radius of gyration (in a solid cylinder $= r\sqrt{\frac{1}{2}}$).
w = weight of shot.
v' = angular velocity.
v = velocity of shot in direction of axis of gun.
n = length of chase containing one complete turn.
s = total length of chase.

Then it may be shown, that

$$P = \frac{W\pi r}{2ngs} \cdot v^2.$$

Now the uniform force which would give the velocity v in the space s, is :—

$$P' = \frac{W}{2gs} \cdot v^2;$$

Therefore :

$$P : P' :: \frac{W\pi r}{2ngs} \cdot v^2 : \frac{\quad}{2gs} \cdot v^2$$

$$:: \frac{\pi r}{m} : 1$$

And if m be the number of calibres in which the complete turn is made, $n = 2mr$,

And $$P' : P :: 1 : \frac{\pi}{2m} :: 1 : \frac{1 \cdot 5708}{m} \ldots.$$

Comparing the work expended :—

$$W' : W :: P'm2r : P2\pi r;$$

But $$P' = P\frac{2m}{\pi};$$

Therefore : $$W' : W :: \frac{P\,4\,m^2 r}{\pi} : P\,2\pi r$$

$$:: \frac{2m^2}{\pi^2} : 1.$$

Taking Whitworth's large gun, where $m = 20$,

$$W' : W :: 100 : 1 \cdot 236.$$

The force P is exerted tangentially, at right angles to the axis of the shot, and its effect may developed into two others :—

1st. A tensile force, tending to tear asunder the chase;

2nd. A twisting force, acting by torsion.

These will be found to be :—

$$\text{Tensile force} \;=\; P \frac{2\pi r}{\sqrt{n^2 + \overline{2\pi r}|^2}}$$

$$\text{Twisting force} \;=\; P \frac{n}{\sqrt{n^2 + \overline{2\pi r}|^2}}.$$

Taking Mr. Whitworth's large gun, the following will be, approximately, the forces required to give translation and rotation, when the shot weighs 80 lbs., and the velocity on leaving the gun is 1,300 feet per second :—

		lbs.
Mean force, to give translation		306,900
Force, to give rotation	3,784	
Friction of shot in grooves, taken at ⅛th pressure	3,012	
		6,796
Total force		313,696

Or, taking the total force at 100, the force to give rotation is 2·16 :—
from which it appears, that even with the rapid twist of Mr. Whitworth's gun, the amount of force expended on the rifling, scarcely exceeds 2 per cent. of the total force of the powder.

INVESTIGATIONS BY MR. CHARLES HENRY BROOKS.

Conditions of Stress of a Cylinder built up of Concentric Rings.

In a homogeneous cylinder of any material, let R_1 and ρ_1 be the external and internal radii respectively, and let f_2 be the normal, or fluid pressure on the exterior, and f_1, that on the interior surface. Then it is shown in Rankine's "Applied Mechanics," Article (273), that the tension per square inch of the internal surface is :—

$$T = \frac{f_1 (R_1^2 + \rho_1^2) - 2 f_2 R_1^2}{R_1^2 - \rho_1^2} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \quad (1)$$

and in the same way it may be shown, that the tension of the external surface is :—

$$\tau_1 = \frac{2 f_1 \rho_1^2 - f_2 (R_1^2 + \rho_1^2)}{R_1^2 - \rho_1^2} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \quad (2).$$

To apply the above to the case of a cylinder composed of four concentric rings :—

Let f_1 = normal pressure on the interior surface.
f_2 = „ „ between the 1st and 2nd rings.
f_3 = „ „ „ 2nd 3rd „
f_4 = „ „ „ 3rd 4th „

Also let R_n and ρ_n be the outer and inner radii, respectively, before it is built up in the cylinder. When a ring is expanded, the greatest tension will be at its inner surface; hence, and in order that the cylinder may bear the strain in the best way, the inner surface of each ring must be strained to some tension T, not exceeding the tensile force of the material.

Then equation (1) being for the first ring, there will be similar equations for the second, third, and fourth rings; but with all the subscript numerals increased

by one, two, and three units respectively; let these be denoted by (1.), (1..), and (1...), and let these four equations be denominated group (1).

Also, for the outer tensions, τ_2, τ_3, and τ_4 of the other three rings, there will be equations similar to (2), but having the subscript numerals increased by one, two, and three units respectively; let this group of equations be (2.), (2..), and (2...),

Now if t be the tension at any radius x, and κ the modulus of extension, then the extension of that radius is $\frac{t\,x}{\kappa}$, and as the outer surface of the first ring is in contact with the inner surface of the second ring:—

$$R_1 + \frac{\tau_1 R_1}{\kappa} = \rho_2 + \frac{T\rho_2}{\kappa} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

Similarly:

$$R_2 + \frac{\tau_2 R_2}{\kappa} = \rho_3 + \frac{T\rho_3}{\kappa} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

And

$$R_3 + \frac{\tau_3 R_3}{\kappa} = \rho_4 + \frac{T\rho_4}{\kappa} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5).$$

Thus there are eleven equations containing five f's, or normal pressures, four τ's, or outer tensions, four R's, or outer radii, and four ρ's, or inner radii; but of these seventeen quantities there may be assumed any particular values for five of the radii, and also one of the normal pressures, say f_1, or f_5 may be taken, so that the unknown quantities being reduced to eleven, can be determined as follows:—

Subtracting (2) from (1), the result gives $\tau_1 = T - f_1 + f_2$ . . . (6).

And in like manner, from the corresponding equations of groups (2.) and (1.) are formed the other members of group (6.), viz.:—

$$\tau_2 = T - f_2 + f_3 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6.)$$
$$\tau_3 = T - f_3 + f_4 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6..)$$
$$\tau_4 = T - f_4 + f_5 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6...)$$

Substituting in (3), the value of τ_1 from (6), and reducing:—

$$\rho_2 = \left(1 - \frac{f_1 - f_2}{T + \kappa}\right) R_1 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

Similarly:

$$\rho_3 = \left(1 - \frac{f_2 - f_3}{T + \kappa}\right) R_2 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (7.)$$

And:

$$\rho_4 = \left(1 - \frac{f_3 - f_4}{T + \kappa}\right) R_3 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (7..)$$

Let, now, R_4 and ρ_4 be assumed of any given value, and let the external pressure $f_5 = 0$:—

Then from (1...):

$$f_4 = T\,\frac{R_4^2 - \rho_4^2}{R_4^2 + \rho_4^2} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (8)$$

And from (7..):

$$f_3 = (\kappa + T)\,\frac{R_3 - \rho_4}{R_3} + f_4 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (9)$$

in which equation R_3 must be assumed;

Then from (1..):

$$\rho_3 = R_3 \sqrt{\frac{2 f_4 + T - f_3}{T + f_3}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (10)$$

Also from (7.):

$$f_2 = \frac{(\kappa + T)\,(R_2 - \rho_3)}{R_2} + f_3 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (.9)$$

in which R_2 must be assumed;

Then from (10.): $$\rho_2 = R_2 \sqrt{\frac{2f_3 + T - f_2}{T + f_2}} \quad . \; . \; . \; . \; . \; (.10)$$

Then from (7), assuming a value for R_1 :—

$$f_1 = \frac{(\kappa + T)(R_1 - \rho_2)}{R_1} + f_2 \quad . \; . \; . \; . \; . \; . \; (..9)$$

And then from (1): $$\rho_1 = R_1 \sqrt{\frac{2f_2 + T - f_1}{T + f_1}} \quad . \; . \; . \; . \; . \; . \; (..10).$$

Having determined the radii and normal pressures by the seven last equations, the outer tension can be obtained from group (6).

EXAMPLE.—Let T = the greatest amount to which the material is to be strained, be = 12 tons per square inch.

κ = modulus of extension = 12,000 tons.
R_4 = outer radius of the 4th shell = 10 inches.
ρ_4 = inner „ „ = 8 „

Then from	(8)	f_4 = 2·634 tons per square inch.
Let		R_3 = 8·003 inches.
Then from	(9)	f_3 = 7·114 tons per square inch.
„	(10)	ρ_3 = 6·1644 inches.
Let		R_2 = 6·1674 „
Then from	(.9)	f_2 = 12·953 tons per square inch.
„	(.10)	ρ_2 = 4·4934 inches.
Let		R_1 = '4·500 „
Then from	(..9)	f_1 = 17·213 tons per square inch.
„	(..10)	ρ_1 = 3·7873 inches.
And from	(6)	τ_1 = 7·740 tons per square inch.
		τ_2 = 6·161 „ „
		τ_3 = 7·520 „ „
		τ_4 = 9·366 „ „

In this example the internal radius is 3·7873 inches, but it is evident from the form of equations (8) to (..10), that the pressures are not altered by taking any multiple of all the radii; and hence, if it were required, that the internal radius should be n inches, all that is necessary to be done is to multiply all the other radii, by the ratio $\frac{n}{3 \cdot 7873}$.

Suppose, for instance, that the internal radius was 4 inches, then multiplying the above radii by $\frac{4}{3 \cdot 7873}$, they become :—

ρ_1 = 4·000	R_1 = 4·7526	∴ thickness of 1st ring	= 0·7526
ρ_2 = 4·7510	R_2 = 6·5137	∴ „ „ 2nd „	= 1·7627
ρ_3 = 6·5106	R_3 = 8·4523	∴ „ „ 3rd „	= 1·9417
ρ_4 = 8·4492	R_4 = 10·5614	∴ „ „ 4th „	= 2·1122

And for the original differences of the radii of the surfaces in contact :—

$$R_1 - \rho_2 = 0 \cdot 0016$$
$$R_2 - \rho_3 = 0 \cdot 0031$$
$$R_3 - \rho_4 = 0 \cdot 0031$$

From this example, part of Fig. 7, (page 302,) has been prepared.

TO FIND THE STATE OF THE CYLINDER DURING THE PROCESS OF CONSTRUCTION.

In this case f_1 and f_5 are each $= 0$, and the tensions of the inner surfaces of the rings will no longer be all equal. Let that of the n^{th} ring be denoted by T_n, and a b c, &c., being given quantities, assume :—

$$T_1 = a f_2 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (11)$$
$$T_2 = b f_2 - c f_3 \quad . \quad . \quad . \quad . \quad . \quad . \quad (12)$$
$$T_3 = d f_3 - e f_4 \quad . \quad . \quad . \quad . \quad . \quad . \quad (13)$$
$$T_4 = g f_4 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (14).$$

Then, subtracting the corresponding members of group (2) from those of (1), observing that T is now T_1 &c., and f_1 and $f_5 = 0$:—

$$\tau_1 = T_1 + f_2 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (15)$$
$$\tau_2 = T_2 - f_2 + f_3 \quad . \quad . \quad . \quad . \quad . \quad . \quad (16)$$
$$\tau_3 = T_3 - f_3 + f_4 \quad . \quad . \quad . \quad . \quad . \quad . \quad (17)$$
$$\tau_4 = T_4 - f_4 \text{*} \quad . \quad . \quad . \quad . \quad . \quad . \quad (18).$$

Substituting these in (3), (4), and (5), observing that the T in (3), (4), and (5), becomes T_2, T_3, and T_4 respectively :—

$$(T_2 + \kappa)\,\rho_2 = (T_1 + \kappa + f_2)\,R_1 \quad . \quad . \quad . \quad . \quad (19)$$
$$(T_3 + \kappa)\,\rho_3 = (T_2 + \kappa - f_2 + f_3)\,R_2 \quad . \quad . \quad . \quad (20)$$
$$(T_4 + \kappa)\,\rho_4 = (T_3 + \kappa - f_3 + f_4)\,R_3 \quad . \quad . \quad . \quad (21).$$

Substituting in the latter equations, the values of $T_1 \ldots . T_4$ from (11) .... (14), the result is :—

$$(b f_2 - c f_3 + \kappa)\,\rho_2 = (a f_2 + \kappa + f_2)\,R_1 \quad . \quad . \quad . \quad (22)$$
$$(d f_3 - e f_4 + \kappa)\,\rho_3 = (b f_2 - c f_3 + \kappa - f_2 + f_3)\,R_2. \quad (23)$$
$$(g f_4 + \kappa)\,\rho_4 \quad = (d f_3 - e f_4 + \kappa - f_3 + f_4)\,R_3. \quad (24).$$

From (22) and (23) :—

$$f_3 = \frac{f_2\,(b\,\rho_2 - \overline{1 + a}\,R_1) + \kappa\,(\rho_2 - R_1)}{c\,\rho_2} = L f_2 + N \text{ suppose} \quad (25)$$

$$f_4 = \frac{f_3\,(d\,\rho_3 - \overline{1 - c}\,R_2) + f_2\,(1 - b)\,R_2 + \kappa\,(\rho_3 - R_2)}{e\,\rho_3}, \text{ which write}$$

$$f_4 = P f_3 + Q f_2 + S;$$

And substituting the value of f_3 from (25) :—

$$f_4 = (P L + Q)\,f_2 + N P + S \quad . \quad . \quad . \quad . \quad . \quad (26);—$$

Also from (24) and (25) :—

$$f_4 = \frac{L\,R_3\,(d - 1)\,f_2 + N\,R_3\,(d - 1) + \kappa\,(R_3 - \rho_4)}{g\,\rho_4 + (e - 1)\,R_3} \quad . \quad . \quad (27).$$

Now to find the condition when only two rings are put together, f_3 is equal zero, and denoting the number of rings by dashes over the f's, equation (25) gives

$$f_2'' = -\frac{N}{L} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (28).$$

---

* By introducing f_1 into (15), and adding together (15) .... (18),

$$\tau_1 + \tau_2 + \tau_3 + \tau_4 = T_1 + T_2 + T_3 + T_4 - f_1;$$

or in any state of the gun, the sum of the outer tensions is less than the sum of the inner tensions by the amount of pressure, per square inch, on the interior.

When three rings are put together, equation (5), and consequently (21), (24), and (27), do not exist; hence making $f_4 = 0$ in (26):—

$$f_2''' = -\frac{\mathrm{N\,P} + \mathrm{S}}{\mathrm{P\,L} + \mathrm{Q}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (29)$$

then from (25):— $$f_3''' = \mathrm{L}\,f_2''' + \mathrm{N} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (30).$$

For four rings put together, equating (26) and (27) will give f_2'''' and then f_3'''' and f_4'''' from (25) and (26). In all these cases the values of the inner and outer tensions are found by (11) to (18).

For example, taking the case already given—

$$a = -\frac{2\,\mathrm{R}_1^2}{\mathrm{R}_1^2 - \rho_1^2} \qquad = -\ 6{\cdot}857$$

$$b = \frac{\mathrm{R}_2^2 + \rho_2^2}{\mathrm{R}_2^2 - \rho_2^2} \qquad = \quad 3{\cdot}2726$$

$$c = \frac{2\,\mathrm{R}_2^2}{\mathrm{R}_2^2 - \rho_2^2} \qquad = \quad 4{\cdot}2724$$

$$d = \frac{\mathrm{R}_3^2 + \rho_3^2}{\mathrm{R}_3^2 - \rho_3^2} \qquad = \quad 3{\cdot}9173$$

$$e = \frac{2\,\mathrm{R}_3^2}{\mathrm{R}_3^2 - \rho_3^2} \qquad = \quad 4{\cdot}9172$$

$$g = \frac{\mathrm{R}_4^2 + \rho_4^2}{\mathrm{R}_4^2 - \rho_4^2} \qquad = \quad 4{\cdot}5556$$

$$\mathrm{L} = \frac{b\rho_2 - \overline{1 + a}\,\mathrm{R}_1}{c\,\rho_2} \qquad = \quad 2{\cdot}1373$$

$$\mathrm{N} = \frac{\kappa\,(\rho_2 - \mathrm{R}_1}{c\,\rho_2} \qquad = -\ 0{\cdot}99902$$

$$\mathrm{P} = \left\{1 - \left(\frac{1 - c}{d}\right)\frac{\mathrm{R}_2}{\rho_3}\right\}\frac{d}{e} \qquad = -\ 1{\cdot}4625$$

$$\mathrm{Q} = \frac{1 - b}{e}\cdot\frac{\mathrm{R}_2}{\rho_3} \qquad = -\ 0.4624$$

$$\mathrm{S} = -\frac{\kappa\,(\mathrm{R}_2 - \rho_3)}{e\,\rho_3} \qquad = -\ 1{\cdot}1876$$

Hence, from equations (28), (29), and (30), the following values are obtained:—

NORMAL PRESSURES DURING CONSTRUCTION.

1 Ring	$f_1' = 0$	$f_2' = 0$	$f_3' = 0$	$f_4' = 0$
2 Rings	$f_1'' = 0$	$f_2'' = 0{\cdot}4674$	$f_3'' = 0$	$f_4'' = 0$
3 Rings	$f_1''' = 0$	$f_2''' = 0{\cdot}9944$	$f_3''' = 1{\cdot}1264$	$f_4''' = 0$
4 Rings	$f_1'''' = 0$	$f_2'''' = 1{\cdot}4713$	$f_3'''' = 2{\cdot}1456$	$f_4'''' = 1{\cdot}270$

Also from (11) to (14) and (15) to (18), are found the tensions of the inner and outer surfaces, the accents denoting, as before, the number of rings put together.

	Inner Surfaces.	Outer Surfaces.
2 Rings.	$T_1'' = -\ 3{\cdot}205$ $T_2'' = 1{\cdot}5297$	$\tau_1'' = -\ 2{\cdot}7376$ $\tau_2'' = 1{\cdot}0623$
3 Rings.	$T_1''' = -\ 6{\cdot}819$ $T_2''' = -\ 1{\cdot}557$ $T_3''' = 4{\cdot}411$	$\tau_1''' = -\ 5{\cdot}825$ $\tau_2''' = -\ 1{\cdot}425$ $\tau_3''' = 3{\cdot}285$
4 Rings.	$T_1'''' = -\ 10{\cdot}086$ $T_2'''' = -\ 4{\cdot}355$ $T_3'''' = 2{\cdot}161$ $T_4'''' = 5{\cdot}778$	$\tau_1'''' = -\ 8{\cdot}615$ $\tau_2'''' = -\ 3{\cdot}680$ $\tau_3'''' = 1{\cdot}285$ $\tau_4'''' = 4{\cdot}508$

From the latter portion of this Table, part of Fig. 7, (page 302,) has been formed. If in the example, (page 331,) R_1 had been taken $= 4{\cdot}501$, instead of $4{\cdot}500$, the value of f_1 would have been found $= 19{\cdot}8917$, and $\rho_1 = 3{\cdot}3827$, the other radii and forces remaining the same, excepting τ_1, which becomes $12 - 19{\cdot}8917 + 12{\cdot}953 = 5{\cdot}051$; and if, as before, the inside radius is increased to 4 inches, the radii will be as under :—

Inner.	Outer.	Thickness.	Differences.
$\rho_1 = 4{\cdot}000$	$R_1 = 5{\cdot}3222$	$1{\cdot}3222$	$R_1 - \rho_2 = {\cdot}0031$
$\rho_2 = 5{\cdot}3191$	$R_2 = 7{\cdot}2928$	$1{\cdot}9737$	$R_2 - \rho_3 = {\cdot}0035$
$\rho_3 = 7{\cdot}2893$	$R_3 = 9{\cdot}4633$	$2{\cdot}1740$	$R_3 - \rho_4 = {\cdot}0035$
$\rho_4 = 9{\cdot}4598$	$R_4 = 11{\cdot}8247$	$2{\cdot}3649$	

With the above radii and value of τ_1, and with the values of $\tau_2\ \tau_3\ \tau_4$ from page 331, Fig. 6, (page 300,) was constructed.

Proceeding as before, the following values are obtained for the normal pressures and tensions during construction :—

NORMAL PRESSURES.

2 Rings	$f_1'' = 0$	$f_2'' = 1{\cdot}0095$	$f_3'' = 0$	$f_4'' = 0$
3 Rings	$f_1''' = 0$	$f_2''' = 1{\cdot}8851$	$f_3''' = 1{\cdot}4082$	$f_4''' = 0$
4 Rings	$f_1'''' = 0$	$f_2'''' = 2{\cdot}6458$	$f_3'''' = 2{\cdot}6314$	$f_4'''' = 1{\cdot}4272$

TENSIONS.

Inner Surfaces.	Outer Surfaces.
$T_1'' = -\ 4.6394$ $T_2'' = 3{\cdot}3037$	$\tau_1'' = -\ 3{\cdot}6299$ $\tau_2'' = 2{\cdot}2942$
$T_1''' = -\ 8{\cdot}6637$ $T_2''' = 0{\cdot}1529$ $T_3''' = 5{\cdot}5163$	$\tau_1''' = -\ 6{\cdot}7786$ $\tau_2''' = -\ 0{\cdot}3240$ $\tau_3''' = 4{\cdot}1081$
$T_1'''' = -\ 12{\cdot}1596$ $T_2'''' = -\ 2{\cdot}5837$ $T_3'''' = 3{\cdot}2900$ $T_4'''' = -\ 6{\cdot}5018$	$\tau_1'''' = -\ 9{\cdot}5138$ $\tau_2'''' = -\ 2{\cdot}5981$ $\tau_3'''' = 2{\cdot}0858$ $\tau_4'''' = 5{\cdot}0746$

From which Figs. 3, 4, and 5, (page 298,) were formed.

If in the example, (page 331,) the value of ρ_4 had been taken $= 8{\cdot}4472$, instead of $8{\cdot}4492$, the inner and outer tensions, when the four rings are put together, would be as follows:—

$$T_1 = -11{\cdot}244 \quad T_2 = -5{\cdot}339 \quad T_3 = 1{\cdot}364 \quad T_4 = 7{\cdot}823$$
$$\tau_1 = -9{\cdot}604 \quad \tau_2 = -4{\cdot}473 \quad \tau_3 = 0{\cdot}577 \quad \tau_4 = 6{\cdot}104$$

In the case where $\rho_4 = 8{\cdot}4492$, the internal force (f_1) necessary to stretch all the rings at their inner surfaces to 12 tons tension, was found to be 17·213 tons, (page 331); but in the case where the value of ρ_4 is too small by ·002 of an inch, the inner surface of the outer ring will be strained to 12 tons by an internal force = 9·908 tons, and the several tensions will be as follows:—

$$T_1 = 2{\cdot}268 \quad T_2 = 4{\cdot}534 \quad T_3 = 7{\cdot}28 \quad T_4 = 12{\cdot}0$$
$$\tau_1 = 0{\cdot}492 \quad \tau_2 = 1{\cdot}570 \quad \tau_3 = 4{\cdot}752 \quad \tau_4 = 9{\cdot}362$$

These are represented by Fig. 8, (page 302).

In the preceding investigation, R and ρ have been taken to denote the original radii of the rings, before being built up in the gun. In reality, however, they denote the expanded radii, and by treating them as such, a different and neater method of investigation would result; but the method here given is preferred, as being that by which the calculations for the diagrams in the body of the work were made.

On the effect of Rotation in correcting the deviation due to want of symmetry of the projectile.

The unsymmetrical form will cause the resistance of the air to have a preponderating effect on one side of the shot. Let the component of this effect perpendicular to the line of flight, be denoted by f; then, this force f may be considered as acting always upon one determinate side of the shot, and consequently, it revolves at the same rate. Setting aside the parabolic form of flight, and supposing that the velocity of the shot, and consequently, the force f are constant, take two rectangular axes perpendicular to the line of flight, the origin in that line, and let the axis of x coincide with the initial direction of the force f, and at any time t, let it make an angle θ with the axis of x.

Then if w = weight of shot, the accelerating force on it will be $\frac{fg}{w} = a$ suppose.

Hence:—
$$\frac{d^2x}{dt^2} = a\cos\theta$$
$$\frac{d^2y}{dt^2} = a\sin\theta.$$

But θ increases uniformly. Let $\theta = nt$, which substitute in the above and integrate, making the initial velocity, zero:—

$$\frac{dx}{dt} = \frac{a\sin nt}{n}$$
$$\frac{dy}{dt} = a\frac{(1-\cos nt)}{n}.$$

Integrating again, so as to make x and y vanish with t:—

$$x = \frac{a}{n^2}(1-\cos nt) \quad . \quad . \quad . \quad . \quad . \quad (1).$$

$$y = \frac{a}{n^2}(nt - \sin nt). \quad . \quad . \quad . \quad . \quad (2).$$

Equation (1) shows, that at the end of each revolution, the point of application of the force f has made no progress in the direction of that force; but from equation (2), the progress at right angles to that direction is $\frac{2a\pi}{n^2}$, and after m revolutions the amount is $\frac{2am\pi}{n^2}$ . . . . (3).

If the force had acted uniformly in the same direction, the deviation would be found as follows :—

$$\frac{d^2 x}{d t^2} = a$$

$$\therefore \frac{d x}{d t} = a t$$

and $$x = \frac{a t^2}{2} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4).$$

Let, now, the time of flight $= \tau$, the number of revolutions in that time $= m$, the deviation, if the force had acted in the same direction $= \delta$; then, $2 \pi m = n \tau$, or $n = \frac{2 \pi m}{\tau}$, which substituted in (3), gives for the deviation of rotating shot in m revolutions, $\frac{a \tau^2}{2 \pi m}$ . . . . (5).

Also (4) gives $\delta = \frac{a \tau^2}{2}$ whence (5) finally becomes $\frac{\delta}{m \pi}$ . . . . (6).

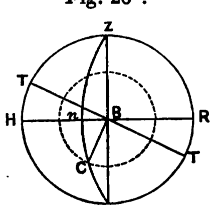
Equations (1) and (2) denote a series of cycloids, and the base of each of them, by dividing equation (6) by m, is $\frac{\delta}{\pi m^2}$; the height of each one is $\frac{\delta}{\pi^2 m^2}$.

If the deviation of a non-rotating shot in 1,000 yards be supposed = 10 yards, then, if the same shot had rotated once every 50 feet, the number of revolutions in the 1,000 yards would be $m = \frac{3{,}000}{50} = 60$, and the deviation, taking $\pi = 3$, would be $\frac{10}{60 \times 3} = \frac{1}{18}$th of a yard = 2 inches, and the length of each of the little cycloids $= \frac{2}{60} = \frac{1}{30}$th of an inch, and the height of each one, $\frac{1}{90}$th of an inch; see page 326. If the re-action of the muzzle of the gun could impress upon the shot a velocity in the direction, opposite to that of the axis of y, and equal to $\frac{a}{n}$, then the shot would be confined to the first of the cycloids, in which it would oscillate, returning, in the above example, to the line of aim once in every 50 feet.

On the Amount of Error produced by the Axis of the Trunnions not being Horizontal.

Assuming that the object fired at is in the horizontal plane, the line of aim will also be horizontal, and independent of the inclination of the trunnions.

Fig. 26*.



Let the intersection B, (Fig. 26*,) of the line of aim and the axis of the gun, be the centre of a sphere H Z R N, then if the line of aim be a diameter of the sphere perpendicular to H R and Z N, the trunnions ought to be parallel to the horizontal line H R; but if not, let them be parallel to T T, inclined to H R at an angle T H B = e; then the elevation of the gun, or depression of the breech, (if measured by a tangent slide,) will be at right angles to T T, and may be represented by a circular arc of which B C is a projection. If the inclination of the trunnions varies while the elevation remains constant, the axis of the gun will describe a conical surface, having B for its vertex and intersecting the sphere, in the small circle described through C.

Draw the great circle Z C N, then the path of the ball will be in that plane, and the angle C Z B, or its measure B n, will be the azimuthal error.

Let $Bn = a$, BC = elevation of gun $= \theta$:—

Then, in the spherical triangle B C n :—

$$\cos CBn = \tan Bn, \cot BC,$$

which gives

$$\tan a = \sin e \tan \theta. \quad \ldots \ldots \quad (1.)$$

There will also be a small error in altitude. The altitude at which the gun really is set to is not B C, but n C,

and

$$\sin \text{true alt} = \sin \theta \cos e \quad \ldots \ldots \quad (2).$$

Example.—Let the tangent slide be set to 10° elevation, and let the trunnions have an accidental error of 2°. Then (1) gives the azimuthal error = 21′ 9″, and by (2), the actual altitude would be 9° 59′ 38″, being an error of 22″; and it is this small error which is generally believed to be the only one.

The following approximate rule is easily deduced from (1). Multiply together the degrees of elevation of the gun and the degrees of inclination of trunnions to the horizon, the product will be the minutes of azimuthal error, to which the horizontal adjustment of the sight may be arranged; or else allow half a yard per mile of range for each minute, and aim that amount to the side which has the most elevated trunnion.

Example.—Let a gun be fired to the west, at an elevation of 10°, on a hill sloping $2\frac{1}{2}$° to the south; then the azimuthal error would be $10 \times 2\frac{1}{2} = 25'$; and if the range were two miles, the gun should be aimed 25 yards to the north of the object fired at.

Mr. BIDDER,—President,—said he felt it was hardly necessary to ask the Meeting to express its acknowledgments, to the Author, for this highly interesting Paper, which touched upon so many points of great importance, and introduced such a variety of matter, requiring careful discussion. As it might be difficult, upon any future occasion, to bring together so many gentlemen whose attention had been directed to the different branches of this great question, which was now exciting so much public interest, it appeared desirable to take advantage of this opportunity, for eliciting information upon the whole subject. The Paper treated, principally, of the construction of artillery; but he hoped some observations would be made upon the best mode of rifling, upon the most effective projectiles, and upon other details connected with the science of gunnery. He also thought, that some attention should be given, to the means of defence against the destructive weapons now being introduced into modern warfare.

Several statements made in the Paper had rather surprised him. The tensile pressure evolved by the explosion of gunpowder was said to amount to from 2,000 to 2,500 atmospheres, or from 14 tons to 17 tons per square inch. He was not prepared to learn, that the tensile force was so great; but the Author had confirmed the statement, by ascertaining the amount of powder required to burst a cylinder of known strength. The President had tested it by the velocity which must be communicated to the projectiles in being urged forward, and the result at which he had arrived, went to show, that the tensile force was rather under-stated than otherwise. Indeed, he believed, the pressure of the gases evolved by the combustion of gunpowder, might be taken at 20 tons per square inch.

Mr. LONGRIDGE remarked, that it might be thought strange, that in the year 1860, he should bring forward the results of experiments which were carried out so long ago as 1855. It had been originally his intention to have laid the subject before the Institution at an earlier period; but on talking over the matter with one of the Past-Presidents, now deceased, that gentleman thought it was hardly advisable to do so, because as Mr. Longridge had taken out a patent for the principle, it might appear that he was making an unwarrantable use of the Institution, as a means of forwarding his own views. Recognising the propriety of the suggestion, he refrained from taking any further steps in the matter at that time. It might be said, that the same objection still applied; but he hoped the Members would acquit him of any such intention. He was aware of the vast amount of time, patience, and money expended by highly intelligent individuals, in endeavouring to effect improvements in weapons of war; and after all that expenditure, there was great probability of their exer-

tions not being attended with success. He had, therefore, long since given up the idea of bringing the matter forward, commercially; and it was only after the bursting of so many cylinders of hydraulic presses, at the launching of the 'Great Eastern,' that he determined to prepare the present Paper. Having done so, he hoped it would induce a good discussion. It might be thought strange, that he should have made no allusion to what had been done by Sir William Armstrong, Mr. Whitworth, and Mr. Mallet. He had avoided doing so, solely because he was not in possession of that accurate information, which the Papers presented to the Institution ought alone to contain. He could not, of course, apply directly to Sir William Armstrong, for he knew the official reserve which in that gentleman's position it was proper to maintain; and he was averse to obtaining such information in an indirect manner. Since the Paper was written, there had appeared in a public journal, a description of the Armstrong gun. There were some portions of that description which led him to think, that the person who wrote it either was not, or did not wish to appear versed in the technical details of the matters he described. At the same time, there was a general description of the process of manufacture, which he presumed the writer had witnessed, and which gave a tolerably clear idea of the leading features of construction. The principle adopted seemed to be the construction of artillery by a series of superposed concentric rings. The bar of iron was coiled round in a spiral form and welded. The same process had been very successfully applied in France, many years ago, for the manufacture of the tyres of locomotive wheels. As regarded guns, Mr. Longridge had formerly tried the system; and he exhibited a piece of a gun so constructed. There was, however, a difficulty in making perfect welds. With the appliances which Sir William Armstrong had at his command, this difficulty had probably been overcome. At the same time, the chief strength of the cylinder so made, was circumferential. The trunnions were shrunk on the gun; consequently, the whole of the recoil was transmitted through the hoops to the trunnions. He doubted, whether it would be possible, in guns of large calibre, constructed upon that plan, to make the welds hold perfectly. He considered, that the transmission of the force of the recoil to the trunnions, should be through iron laid longitudinally. If some plan of that kind were not adopted, the hoops of the guns would shake loose and give way, although smaller guns made upon that plan had been successful. He had read the article in the journal with pleasure, because it convinced him, that a step was at last being taken in the right direction.

With respect to Mr. Whitworth's proceedings, he appeared to be directing his attention rather to the best modes of rifling,

than to making a strong gun. As regarded Mr. Mallet, his was an endeavour to carry out the principle of hoops upon a large scale. Mr. Longridge did not like to call it a failure; he would rather say it was an unsuccessful experiment. The principle Mr. Mallet had in view was the correct one; it was a step in the right direction; but it was not successful, because sufficient attention had not been paid to the accuracy of dimensions and of workmanship, which the system of rings involved. Mr. Longridge had written to Mr. Mallet for particulars as to the size of the rings; but as that gentleman professed to be preparing a Paper upon the subject, for the Institution, he naturally preferred to retain the information, until such time as he could bring it forward himself.

Before the discussson commenced it might be advisable to explain the objects exhibited, and also to call attention to the diagrams of tension; (Figs. 2, 3, 4, 5, 6, 7, and 8, pages 217, 298, 300, and 302). He would first allude to the brass cylinders referred to in the Table, (page 307,) and to the method of using them shown in Fig. 11. One of these cylinders, without wire, was bulged by a charge of 60 grains of powder. If firing had been continued with the same charge, no doubt the cylinder would have been burst. Another cylinder, with four coils of wire, was tested with 200 grains of powder, and was fired repeatedly, without any effect being produced. Another cylinder, with two coils of wire, was fired first with 90 grains without effect. The wire at one end was then loosened, and 100 grains of powder were put in; when the cylinder became curiously bulged at one end.

With respect to the cast-iron cylinders, Fig. 17, (page 316,) represented the last cylinder mentioned, with ten coils of wire. It was filled with powder, the end was plugged up, and the powder was fired repeatedly, without producing any effect upon the cylinder. The flange had been since accidentally broken off, when it was found, that the side of the cylinder had been sheared off from the top flange. The top flange was not able to expand; but the part of the side, covered with the wire, did expand, and was sheared off. That, however, did not affect the principle, as applied to artillery. He would mention the extraordinary effect which the powder had upon the cast iron. The plug was the exact size of the cylinder when made. After being fired six, or seven times, the plug was grooved in more than $\frac{1}{8}$th of an inch, by the action of the powder, and the recoil from this, on to the flange, caused a groove in the opposite direction.

When the Paper was written, he had not been able to find any information respecting the actual amount of deterioration, which cast iron, in the interior of a gun, underwent by cooling; nor had he yet been able to do so. But the results of some experiments made by

Captain (now Colonel Sir H.) James, R.E.[1], (Assoc. Inst. C.E.,) for the Commissioners on the use of iron for railway structures, bore somewhat upon the point. Captain James took a small bar of cast iron, $\frac{3}{4}$ths of an inch square, and then cut a bar of the same size out of the centre of a bar 3 inches square. Those bars were then tried as to their resistance to a crushing force, and also as to their transverse strength. The reduction in resistance of the latter bar to a crushing force was 43 per cent., and in transverse strength 42 per cent. Mr. Longridge felt confident, that in a mass of metal, such as was required for a 68-pounder gun, the loss of strength would be at least 50 per cent. When that was combined with the loss of strength due to a homogeneous cylinder, it easily explained the bursting of the hydraulic presses, to which allusion had been made. If the tensile strength of cast iron was taken at 8 tons per square inch, and Professor Barlow's formula was used, the pressure which would burst the cylinder of a hydraulic press 10 inches in diameter, would be 5·54 tons per square inch. But inasmuch as the tensile strength in the interior was reduced from 8 tons to 4 tons, the pressure at which it would burst would be 2·77 tons. If the more accurate formula of Lamé was employed, afterwards deduced by Dr. Hart, in his calculations for Mr. Mallet, and by Mr. C. H. Brooks, in his investigation for the Author, and also arrived at by Professor Rankine, by another method,[2] the bursting strength would be $3\frac{1}{3}$ tons. Mr. Longridge believed this last formula was the most accurate yet discovered. In the Paper, before the Institution, Professor Barlow's formula was mentioned, because he was the first to point out the cause of weakness in hydraulic presses. But he did not think that Professor Barlow was quite accurate in the investigation, the chief error being in the assumption, that the area of the section of the cylinder remained a constant quantity. Now inasmuch as the iron, by the force of the pressure, became compressed, that must be taken into account in the equations.

In Fig. 2, (page 297,) the line H I represented the state of tension of the particles of a homogeneous cylinder, strained by an internal pressure, according to the true formula. The line H *i* represented the same, according to Barlow's formula. Consequently, the absolute resisting strength was the area of the curve G H I F, or G H *i* F, as one, or the other formula was employed. Now the object to be attained was, that when the particle at G was strained to the extent denoted by G H, the particles at K and F should be equally strained at the same moment. The only way to accomplish that, was to put the particles from G to N

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[1] *Vide* "Report of Commissioners on Railway Structures, 1849," page 257.
[2] *Vide* "Manual of Applied Mechanics," page 293.

into an initial state of compression. The strain of the particles, before explosion, was represented by the curve L N M. What took place when the explosion occurred, might be thus described:—

L was raised to H: and every point from G to F was raised up to the tension denoted by its projection on the line H O. The total strength was represented by the area L H O M N L, which was equal to the rectangle G H O E. That was the way to get, theoretically, the strongest gun. With reference to the system of construction by means of hoops, referring to Fig. 3, (page 298,) as soon as the second hoop A_2 was put on, with proper tension, it brought the inner one A_1 into a state of compression; the parts shaded below the diametral line representing compression, and those above exhibiting tension. But at the junction of the hoops there was an abrupt change. When the third ring A_3 was put on, the inner ring A_1 was still more compressed. The second one A_2 was brought down almost to the normal line, while the third A_3 was in a state of tension. When the fourth ring, A_4 was put on, the first ring was put in a still greater state of compression, as also the second A_2, and the tension of the third A_3 was reduced. When the pressure was brought on the inside, it ought to raise the tension of the whole of the rings to their ultimate tensile force. But as was shown in Fig. 6, (page 300,) it only did so as regarded the inner surfaces of the rings. The inner one was raised 12 tons, so that the inner surfaces were strained to 12 tons uniformly, but the outer surfaces could not be so, for each ring, being homogeneous, must follow the law shown in Fig. 2, (page 297). The state of tension was represented by the series of curves a b, c d, &c. &c., (Fig. 6); therefore the aggregate strength would be less than the rectangle C a $\times$ C D, by the area of all the spaces a b c, c d e, &c. That would be the case, if a gun was constructed with rings accurately made, according to theory; but supposing the fourth ring to be $\frac{1}{500}$th part of an inch too small,—in the case of an 8-inch gun, the result was shown in Figs. 7 and 8, (page 302). The initial tension of the outer ring B_4 was increased, whilst that of the second ring was decreased, and the initial compression of the inner rings was increased. When the internal pressure was brought on, the inner surface of the outer ring was strained to its full tensile force; the next was strained about one half, the next one third, and the inner ring was scarcely strained at all. Thus there was a great reduction of strength, from even an error of $\frac{1}{500}$th of an inch. This example showed, that if the strength of a homogeneous cylinder of wrought iron was 100, when rings were applied in a proper manner, the strength would be raised to 191. But the error of $\frac{1}{500}$th part of an inch, would reduce the strength to 110. If, on the other hand, all the rings had been brought up to the full tension, then the strength would be 218, or

nearly two and a quarter times the strength of the homogeneous cylinder. This was what Mr. Longridge had been trying to do with wires, which were in every way equivalent to very numerous and thin rings, so that every point could be brought almost up to the ultimate strain which the wire would bear. He would also state, that not only could wire be applied, with the greatest facility, exactly in the way indicated by theory, but it was the strongest material known. A piece of iron which would bear a tensile force of 20 tons per square inch in the bar, would bear 40 tons per square inch, when made into small wire; and steel wire had borne from 120 tons to 130 tons per square inch. Although the experiments he had made had been on a small scale, he hoped they would be regarded as valuable, in confirming what theory pointed out. He had so strong a faith in this theory, that he should have no hesitation in working upon it.

The present question reminded him of the course of events in reference to the construction of girders. In the first instance simple beams of cast iron were used. Tredgold then suggested the double T form, which gave greatly increased strength. Mr. Eaton Hodgkinson, (Hon. M. Inst. C.E.,) followed, and brought out the best form of beam, theoretically considered. Subsequently, the new and stronger material of wrought iron was introduced, and was carried to a high state of development in the Britannia Bridge. In all this the indications of theory had been followed, and he hoped the same would occur with regard to guns. He looked upon the Armstrong and Whitworth guns, as steps in the right direction. Hoops were used, but it was at present doubtful, whether they were being applied with that care, with respect to tension, which theory demanded. Still, it was a step in the right direction, and he had no doubt further improvements would be made, and that before many years, the value of the system of construction now advocated, and the applicability of wire, would be fully recognized.

Mr. Alfred Longsdon stated,—through the Secretary,—that he was desirous of explaining the circumstances in connection with the bursting of Mr. Krüpp's gun, at Woolwich, in 1853, alluded to in the Paper. This explanation was essential, in justice to Mr. Krüpp, as, if the cause of the bursting was not made apparent, an erroneous idea of cast steel and of its application to ordnance might be the result. The gun which burst at Woolwich was designed for an ordinary 68-pounder round shot, but during the proof a shot weighing 259 lbs. was used. It was, moreover an expanding shot, having a wrought iron ring, of a V shape in section, fitted on to the end. When the explosion of the powder took place, this ring was broken, and was forced along the body of the shot, cutting up the cast iron to the extent of from 6 inches to 8 inches. The pieces of the shot, thus cut off, together with the

broken ring, completely wedged the shot in the gun, at about the second reinforce, and the natural consequence was, that the gases having no means of escape, burst the gun. The shot was not forced through the gun, but when the bursting took place, it was carried, with the muzzle of the gun, forward to the butt, and was jerked out at the broken end, and thrown over the butt into the convict sheds. The shot was, evidently, the whole and sole cause of the bursting, and no blame could be attached to the metal of the gun. That cast steel was specially adapted to the purposes of ordnance had now been proved by other Governments, and Mr. Krüpp had made a very large number, particularly of rifled guns, without one having burst. As a proof of the tenacity of the steel, it might be mentioned, that a 12-pounder howitzer gun was sent, by Mr. Krüpp, to Woolwich, for the purpose of being tested, as severely as it could be, and notwithstanding that the gun was completely filled to the muzzle with powder, shots, and broken shells, it could not be burst, and it was returned with the cascable knocked off by the recoil; the gun having been thrown high up into the air by the force of the explosion.

Mr. C. H. Gregory, V.P., said, having been for two, or three years a member of the Select Committee of Ordnance, he begged to offer a few observations upon the Paper before the Institution. If he differed from the Author in one, or two points, both as to his practical details, and as to the implied incompetence of the Ordnance Select Committee, he could not withhold his testimony to the excellence of the Paper, in which was developed, as he believed, one of the most important principles, in the manufacture of large guns. He agreed with the views expressed, that it was impossible, in a large gun, to get the ultimate strength out of a homogeneous material, such as cast metal, or wrought iron forged in large masses; and he believed it was an important improvement to build up large guns, on the principle which had been so well explained. But with regard to the manner in which that principle was to be practically applied, he did not quite agree with Mr. Longridge. Perhaps he could best illustrate his views, by referring to one, or two cases which had come before him officially, as a member of the Ordnance Select Committee. Soon after the commencement of the war with Russia, the civil element was introduced into the Committee. Besides himself and another Engineer, the Professor of Mathematics at the Royal Military Academy, the Chemist to the Ordnance, and another gentleman distinguished in physical science, were made members. There was, at all events, it might be imagined, sufficient of the civil element to assist the military members of the Committee in coming to a right conclusion. The Select Committee was now, however, composed exclusively of military members.

The idea of constructing guns by hoops laid upon bars was not a new one. Some of the oldest guns were made in that way; although no doubt in ignorance of the principles elucidated in the Paper, and without any attention whatever being paid to those principles. If he did not quite agree with the Author, that the Civil Engineer was more qualified to deal with the designing of guns than Artillery Officers, it might in some measure be, because this principle first came to his knowledge through an Artillery Officer, Captain Blakely, who, he thought, had dealt with the matter more practically than Mr. Longridge. The form of Captain Blakely's first gun was shown in Fig. 9 (page 304). When Mr. Gregory first saw it, he ventured to predict, that it would fail at the breech; and he suggested, that it would be better for Captain Blakely to make a gun with the probability of the breech being preserved, rather than expose himself to the risk of failure. The breech of that gun did blow out. He admitted that the Select Committee did not, at the time, understand the principle of that gun, as their report showed; but they afterwards became sensible of their mistake, and, he thought, were disposed to recognise the merits of the principle. If the officer who brought it forward, had not received that encouragement which might have been expected, it had been owing to the belief on the part of some members of the Select Committee, that the principle was not new. But the question of priority of invention was not now before the Institution, and he would, therefore, only say, that whoever first introduced it, in a practical way, deserved the utmost credit, and, some solid reward from the country. Whilst Captain Blakely's gun was before the Committee, Mr. Longridge showed and explained to him a drawing of the model, Fig. 12 (page 308). He then pointed out the probable failure that would ensue, from the want of means to keep the breech on, and the absence of longitudinal strength; and where a gun had to be severely tested, these were important considerations. It had been stated, that the gun burst because it was not properly tested, and that the breech of the gun should have been placed against a solid bearing; but he submitted, that guns should bear due proof without such support. While recognising the excellence of the principle, he had told Mr. Longridge, that the same principle, in a more practical form, was already before the Select Committee. He pointed out, that the mode in which the principle was applied, though theoretically more perfect than that of Captain Blakely, would be liable to objection, as there would be no certainty in coiling on the wire with the proper tension, and that theoretical perfection could not be insured. He considered, also, that there would be a difficulty in securing the wire from injury, for if the end were detached, or one wire were broken, there did not seem to be anything to prevent the whole coil from

unravelling. The mode of shrinking on hoops, or tubes, one over the other, though not so perfect theoretically, was less liable to irregularities of manufacture, or to subsequent injury. Where wire was used, there would be a difficulty in effecting longitudinal strength, and in securing the breech, which were essential conditions to the safety of a gun. When hoops, or tubes were employed, upon a shell, or core, the breech could be made more a part of the gun itself, and longitudinal strength could be better attained. That view had received confirmation, from the Armstrong gun, which had a strong and secure breech. Owing partly to the descriptions which had appeared in the journals, and partly to the statements of Sir William Armstrong himself, the particulars with regard to that gun were no longer secret. It was, therefore, no breach of confidence to intimate an opinion, that the construction of that gun was based, with some variations, upon the principles of construction brought forward by Captain Blakely; and the very ingenious combinations of the Armstrong gun had produced a strong gun with a secure breech. Mr. Mallet's gun, known as the 'Monster Mortar,' was partly made upon the same principle; but here again had occurred the difficulty of fastening on the breech. Mr. Mallet seemed to under-rate the enormous power of the explosive gases from gunpowder. There was a series of rings, and the breech was held on to the muzzle piece, by a number of longitudinal wrought-iron bars, which appeared to be inadequate for the explosion of a full charge. Mr. Whitworth's guns seemed, by the description in the journals and the statements in the House of Commons, to have been built somewhat similarly to those of Sir William Armstrong. Therefore, there were three, or four of the most celebrated modern guns, in which the value of the principle advocated in the Paper had been practically recognized.

Mr. Longridge had alluded to several rifled guns having burst. It must not be forgotten, that some of those guns had been bored out to a larger chase than the blocks were originally intended for, and so far, the test was unfair. Some of the Lancaster guns had burst; while the shells from those guns sometimes attained great precision, and at other times they flew wide. These results, he thought, might have occurred from a want of concentricity in the axis of the shell and the axis of the gun, in which case, there was a tendency to jam and burst the gun. With regard to the guns which had burst after being bored upon Mr. Whitworth's principle, he believed that the hard metal shot was made to be a close fit to the polygonal rifled bore. This arrangement might answer very well, so long as the bearing surfaces were as clean as those of a piece of machinery, and the work was done with the precision of Mr. Whitworth's tools. But if inferior work were used, or when the bore became foul, he thought a hard metal shot, fitting close to a rifled

bore, would have a tendency to burst the gun. He did not say this might not be overcome, with a gun built upon Captain Blakely's principle: at the same time it was rather a hard tax upon cast iron, which might be capable of standing its work with a smooth bore.

It was not necessary, that he should defend all the acts of the Select Committee. He believed they had done good service, and had helped good inventions, rather than thrown impediments in the way, as some disappointed inventors seemed to think. When he first became a member of that Committee, about thirty inventions were submitted for consideration every week. This involved a large amount of work; and if occasional errors of judgment had occurred, that must be the excuse. If Sir W. Armstrong's gun was not recommended, with all the promptitude which some considered due to it, it should be remembered, that without careful experiment, the Committee would have incurred grave responsibility in suggesting such a revolution. It was felt, that in so important a matter, the change should be gradual. After seeing the wonderful practice with that gun, the Committee had, he considered, given it due encouragement, although it was not the Select Committee who advised its adoption, to the extent to which it was now decided to be used.

As a Civil Engineer, he was not likely to undervalue the powers of his own profession, but he must say, that he thought the artillery officer who used the guns had some qualifications for the successful designing of guns, which even the Civil Engineer could not possess. He did not think an artillery officer would have proposed such a projectile, as that alluded to by Mr. Longridge, as having caused the fracture of one of his guns. Those who used guns would often think of some important point, which would escape the attention of civilians, however scientific, or practical.

With regard to the Select Committee, he hoped it was no breach of official propriety to say, that inventions were repeatedly referred back, because some influence was used with the Government, to set aside the recommendations of the Committee. He believed it could be shown, that thousands of pounds,—he might perhaps almost say, hundreds of thousands of pounds,—had been squandered, in trying, at the public expense, inventions which the Committee had pointed out to be utterly valueless, and which afterwards proved to be failures. In the desire to avoid a waste of the public money, and in the multitude of inventions upon which they were called upon to decide, the Select Committee might sometimes have committed errors; but many important improvements had been encouraged and developed, and he believed the Committee had merited the confidence of the Government and the thanks of the country.

Captain BLAKELY, R.A., while appreciating the kind mention which had been made of his efforts to improve the construction of guns, thought undue weight had been attached to the circumstance of his having preceded Mr. Longridge by a short time, in the introduction of his principle before the Government authorities. It was well known, that about the same time (1855), Mr. Mallet brought the same general theory of the matter before the Royal Irish Academy.[1] Mr. Mallet and Captain Blakely took a slightly different view of the mode of carrying out the principle, to that adopted by Mr. Longridge. As the method of using wire had been already fully described, he would confine his remarks, chiefly, to the views entertained by Mr. Mallet and himself. They wished to build up a gun of concentric cylinders, each slightly compressing that within it, thus only approximating to the theoretical perfection, which, doubtless, could be gained with wire, better than with any other material. Mr. Mallet and Captain Blakely only seemed to differ on one point, and that an unimportant one. The former proposed wrought iron throughout, whilst the latter had thought steel, or cast iron, more suitable for the interior of the gun. He was now speaking of a method of construction proposed six years ago, when only iron shot were fired. The introduction of a leaden coating to projectiles, somewhat lessened his objection to forged iron, as a material for the interior of cannon. The barrel of the Armstrong gun was an example of the mode of construction recommended by Mr. Mallet. Any person following the instructions contained in his treatise on artillery,[2] could scarcely fail to make a barrel like that of the Armstrong gun. Captain Blakely had made some experiments with cast iron for the centre of the gun. The first had already been alluded to, as having had the breech blown out. It was made as an 18-pounder gun, and was very thin, and it was intended to fire about 3 lbs. of powder, with the 18-lbs. shot. A long time having elapsed, before he received an answer to his application to have the gun tried at Woolwich, he tested it personally, with the assistance of the staff of the Butterley Iron Company. He then found it to be an excellent light 18-pounder. Although weighing only 15 cwt., it was safe to fire with 4 lbs. of powder and an 18-lbs. shot. It was afterwards bored out to the calibre of a 24-pounder, (Fig. 9, page 304,) when the cast iron was not more than a quarter of an inch thick. In thus increasing the size of the bore, the true proportions were necessarily lost, but he wanted to ascertain how far the thickness of the metal could be safely reduced. The gun was in this state, when, at length, permission

[1] *Vide* "Transactions of the Royal Irish Academy," vol. xxiii., part I., page 141. 4to. Dublin, 1856.

[2] *Vide* "On the Physical Conditions involved in the Construction of Artillery, etc." By R. Mallet. 4to. Dublin, 1856.

was granted to have it tried at Woolwich. There it was fired several times, first with 4 lbs. of powder and a 24-lbs. shot, the maximum charge he expected it to bear, then with gradually increased charges of powder, and ultimately, for three rounds, with 8 lbs. of powder and a 24-lbs. shot. It burst, of course, as was intended, and exactly where Mr. Gregory had predicted. Whilst this experiment was going on, the gun, (Fig. 10, page 304,) was being made. It was simply a cast-iron gun, cylindrical from the breech to the trunnion, having three wrought-iron hoops shrunk on it, with a tension not very accurately ascertained. Yet that gun was proved to be one of the strongest ever made. For the sake of comparative experiment, the Ordnance Select Committee had a cast-iron gun and a brass gun of the same size fired, round for round, with this gun. This experiment was made at Shoeburyness in 1855 and 1856, and lasted over a period of nineteen months. The result showed, that his gun was more durable than the cast-iron gun, in the proportion of about 7 to 1, and than the brass gun, by about 3 to 1. The Table, (page 305,) showed the exact number of shot fired. Guns made on that model would be of simple construction and be useful for many purposes, particularly for naval rifled cannon. The result of the experiment just alluded to, caused Lord Panmure, the then Secretary of State for War, to order a 68-pounder and a 10-inch gun to be made, at Woolwich, further to test the principle, and now, he was happy to say, large numbers of similar guns were being made for the Royal Navy. Whilst advocating this system, however, Captain Blakely wished it to be understood, that he fully agreed, that greater strength could be obtained by the use of wire, than in any other manner. Indeed if monster cannon were wanted,—mortars to throw shells of several tons weight, to a distance of several miles, for example,—recourse must be had to wire. He believed that such guns could be made by that system; but he doubted if they could be manufactured in any other way.

Mr. Bashley Britten said, one of the reasons assigned in the Paper, for its being necessary to discover a better method of making guns, than that which had previously existed, was that for rifled guns, with elongated projectiles without windage, cast iron would not stand. It had recently been asserted, that all the cast-iron guns rifled in England had, without a single exception, been burst, before the experimental trials were concluded. This statement was calculated seriously to mislead. At the same time it was remarked, that the French had succeeded in rifling a great number of old iron ordnance. This fact proved, that cast iron was a better material than it was generally considered to be. He adverted to this point, because, for many years past, he had been endeavouring to improve the efficiency of the existing stock

of guns, by converting them into rifled cannon. He had made a considerable number of experiments, during the last six years, at Shoeburyness, and would state, generally, the facts elicited. He had, altogether, tried seven guns, made entirely of cast iron. Five of these were ordinary service guns, not strengthened in any way. They had been put into a lathe, and five shallow grooves, each $\frac{1}{16}$th of an inch deep, had been cut down the bore. Two of these were 9-pounder field-guns, weighing 17 cwt.; two were 32-pounders, weighing about 56 cwt.; and one was a 68-pounder, weighing 95 cwt. There had been fired from the 9-pounder guns fifty-four rounds; from the 32-pounders, one hundred and eighty-one rounds of heavy shells, with heavy charges of powder; and from the 68-pounder, twenty-six rounds of shells, weighing from 90 lbs. to 100 lbs. each, and capable of containing nearly 8 lbs. of bursting powder. Up to this time, no gun to which this system had been applied, had been burst, or injured. The rifling of these guns had enabled conical instead of round shot to be used, and the projectiles were, generally, about 50 per cent. heavier than the service solid shot; whilst the conical projectiles were shells, possessing a capacity for a bursting charge three times as great as that of the spherical shells. With these shells and the rifled guns, an increased range of several hundred yards had been obtained, at 10° elevation, beyond the range of similar guns, before they were rifled. The results of some experiments with the 32-pounder guns, as smooth bores, and the same guns when rifled, were given in the following Table:—

Rifled 32-pounder Cast-iron Service Gun, (Unstrengthened). Weight 55¾ cwt., bore 6·41 inches. Weight of projectile 49 lbs., diameter 6·33 inches. Charge of Powder 6 lbs.						Smooth-bore 32-pounder Cast-iron Service Gun. Weight 56 cwt., bore 6·41 inches. Service solid shot, weighing 32 lbs. Charge of Powder 10 lbs.					
Elevation 4⅓°.			Elevation 10°.			Elevation 5⅜°.			Elevation 10⅜°.		
Recoil.	Range, first graze.	Deviation from line of aim.	Recoil.	Range, first graze.	Deviation from line of aim.	Recoil.	Range, first graze.	Deviation from line of aim.	Recoil.	Range, first graze.	Deviation from line of aim.
Ft. In.	Yards.	Yards.	Ft. In.	Yards.	Yards.	Ft. In.	Yards.	Yards.	Ft. In.	Yards.	Yards.
9 7	2,026	In line	8 9	3,530	3 left	9 9	2,030	6 left	9 0	2,768	24 right
9 7	2,125	5⅓ right	8 9	3,556	5 right	9 8	1,969	8⅓ right	9 0	2,751	34 right
9 9	2,100	2 left	8 10	3,690	6 left	9 5	2,021	9 right	9 6	2,802	22 left
9 4	2,078	2 right	8 10	3,560	4 right	9 5	1,885	10 left	9 5	2,676	17 right
9 3	2,063	5⅓ left	9 1	3,665	In line	9 4	1,980	36 right	9 3	2,665	14 right
			9 2	3,570	1 right	9 6	1,980	In line	9 6	2,768	40 left

It would thus be seen, that at an elevation of 10°·22′, the smooth bore, with a range of only 2,724 yards, varied in accuracy to the average extent of 23 yards from the line of aim, while the rifled gun, at 10°, varied at a range of 3,562 yards, only 3¾ yards.

These facts afforded a practical refutation of the assertion, that

the cast-iron guns were incapable of being rifled. He believed, that at Woolwich, on shipboard, and at the various home and colonial stations, there were not less than fourteen, or fifteen thousand of these guns. If they could not be improved up to something like the new standard now looked for in artillery, no doubt they must be sacrificed, at any cost, and others of a more elaborate and expensive workmanship be substituted. He ventured to assert, however, not only that these guns might all be rifled, but that they did not positively require strengthening for this purpose. They could be strengthened in the manner that had been suggested, and perhaps it might be advisable to do so, because if stronger, heavier projectiles could be employed. But he thought they should first be rifled, and then, if desirable, they might be adapted for heavier work. The rifling need not cost more than about thirty shillings for each gun, and the operation could be effected with portable, hand-labour rifling machines, either on board ship, or wherever the guns might happen to be. It was not necessary that they should all be brought to Woolwich. He was convinced, that these guns did not absolutely need strengthening previously to being rifled, because he contended, that the recoil of a gun afforded a comparative indication of the strain from within; and the superior results, he had mentioned, were obtained with less recoil than was usual with the service charges. The average recoil of a 32-pounder gun, on the platform at Shoeburyness, with the service charge of 10 lbs. of powder and a 32-lbs. solid shot, was 9 feet 3 inches. The rifled gun, with a 50-lbs. shell and 6 lbs. of powder, only recoiled 8 feet 11 inches, and with 5 lbs. of powder, only 7 feet, or 2 feet 3 inches less than the usual recoil. This fact was inconsistent with the idea, that the rifled gun was endangered by additional strain. He was aware that several attempts to rifle cast-iron guns had failed; and it was not surprising, that frequent failures should beget mistrust. But he believed these failures had arisen, because the guns were tried in such a way as to involve an immense amount of unnecessary strain. If the bore of a gun was converted into a female screw, having a sharp pitch, and the attempt was then made to drive through it a hard iron shot with a velocity of 2,000 feet per second, the friction on the sides of the gun would be so enormous, that the gun must have extraordinary strength to withstand it. This, he imagined, was the case with the cast-iron 95-cwt. guns, having bores only about 5 inches in diameter, rifled and burst by Mr. Whitworth; and it was the same, though in a less degree, with the Lancaster gun. The fact of its having been found necessary to make the Lancaster shells of wrought, instead of cast iron, proved this. The shot was liable to get jammed in the bore, and then, if the gun was not of great strength, it burst. It should not,

however, be argued from those failures, that Mr. Britten's system must also prove abortive.

In considering the question of additional strain on rifled guns, the character of the projectile was a most essential point. He used a compound shell, on the principle of the Enfield bullet. The body of the projectile was of cast iron, and a band of lead was secured firmly to the iron, so that no disruption could take place. The soft metal was placed just where it was calculated to expand, to fill the bore, and to take the rifling. By examining the shells which had been fired, it would be seen, that the lead only extended for about 2 inches up the sides, where the marks of the rifling showed itself. All the hold of the rifling was on the five thin projections of soft lead, $\frac{1}{16}$th of an inch thick. It was impossible they could offer sufficient opposition to the egress of the shell, to cause the gun to burst. Some of these shells had been fired with such heavy charges of powder, that the lead had been entirely sheared away by the rifling, but this was all that could happen. The shot could never get locked in the bore.

For field artillery, he was certainly of opinion, that cast iron was unsuitable. Small wrought-iron, or steel, guns could be easily made, having the important advantage of superior lightness. But as the size of forgings increased, the expense was so great as to become a serious question; and the saving of a few cwt. in ship guns could not in itself be worth the outlay. Some idea of the comparative cost of cast and wrought-iron guns might be formed from the fact, that the Armstrong 12-pounder 3-inch gun, weighing 8 cwt., cost, it was said, £250, while the value of the cast-iron 9-pounder, weighing 17 cwt., was less than £20. With one of these 9-pounder guns, he had obtained a range, at 10° elevation, of 3,250 yards, with $1\frac{3}{4}$ lb. of powder and a shell weighing 14 lbs. It had recently been stated in the House of Commons, that the range of the Armstrong 12-pounder field gun, fired at 7° elevation, was about 2,480 yards, and at 9° elevation, 3,000 yards, which Mr. Britten had equalled in 1855.

So much had been recently said about long ranges of five miles, that it might seem trifling to talk of only two, or three thousand yards. But he gathered from the opinions of practical artillerists, that a range of five miles was, in itself, of comparatively little use. At that distance, it could never be expected to hit a moving object like a ship. To do so, the exact position of the object must first be determined, and then the elevation must be calculated, so that the shot might be sent up into the sky, and be literally dropped from the clouds right down upon the deck. It seemed to him, that some great authorities on rifled cannon were engaging in a contest about a minor point, in constructing guns of small bore,

with the single object of enormous length of range. There was no doubt, that a small bore would give great range, at high angles of elevation, but it did so at the sacrifice of that which was of far more value, great capacity of shells. Small holes, caused by shot only 3 inches, or 4 inches in diameter, through the sides of a ship, would never sink her. But a shell, containing 8 lbs., or 10 lbs. of powder, bursting between decks, would so rend everything asunder, that a few such shocks would sink the largest line-of-battle ship afloat. Such shells as these he had fired from a common cast-iron 8-inch rifled gun; and at the practicable distance of two miles, they might be so fired, as scarcely ever to miss an object the size of a gun boat. It might be advisable to have on board all ships of war, a few small-bore guns, for skirmishing at long ranges, but they would never decide actions. Battles would be fought and won at nearer ranges; and directly the distance was shortened to within two miles, all the advantage of the expensive wrought-iron guns ceased, and the cheap cast-iron ordnance would then be just as effective,—indeed, far more so, if of larger calibre.

The performance of different guns should not be compared for range alone. The charge of powder, the size of the bore, and the resistance of the air to the larger projectiles, and the probable efficiency and actual results should all be taken into consideration. That was the most perfect instrument, which used to the best advantage the power applied to it. He contended that no results, hitherto obtained, with any breech-loading cannon had, when all these points were considered, established any superiority in breech-loaders over the far more easily constructed, less complicated, and less delicate guns which were loaded from the muzzle. Whenever screws formed a portion of a gun, there was, necessarily, considerable liability to injury from rust and other causes; and bearing in mind the rough work that guns were subjected to, involving long-continued exposure to damp and wet for sea and garrison service, he could not but think, that this was a serious objection. It might be true, that men would not be so much exposed at port holes when loading breech-loaders. But the introduction of rifled guns would cause actions to be fought at long ranges; and when, for instance, ships were engaged only half-a-mile apart, it would be impossible to see whether men were exposed, or not, during the process of loading.

Mr. Britten considered there was a great deal of misconception, as to the advantages to be obtained by the employment of small-bore guns and projectiles of great length. At very high elevations, such projectiles, undoubtedly, had longer range, because from their greater weight and smaller area of transverse section, they were less impeded by the air, and maintained their velocity during a longer time of flight. But it was a mistake to suppose, that at low

elevations they had any advantage, in point of range, over the larger projectiles which he had fired from rifled service guns. In order that this important point should be fully understood, he had prepared a Table, giving the results of his experiments, and he had added the results, as published in the newspapers, obtained with the Armstrong and the Whitworth guns:—

	Bore.		Charge of Powder.	Projectile.		Elevation.	Range.	Mean Velocity per Second.
	Diameter	Area.		Weight.	Capacity			
	Inches.	Inches.	lbs.	lbs.	lbs.	Degrees.	Yards.	Feet.
Rifled 9-pounder Service Gun, Cast Iron, 17 cwt.	4·2	13·1	$1\frac{3}{4}$	14	6 oz.	5	2,000	Not ob-
	,,	,,	,,	,,	,,	10	3,200	served.
Rifled 32-pounder Service Gun, Cast Iron, 56 cwt.	6·41	32·2	6	49	$3\frac{3}{4}$	3	1,600	1,122
	,,	,,	,,	,,	,,	$4\frac{1}{2}$	2,100	1,016
	,,	,,	,,	,,	,,	$8\frac{1}{4}$	3,100	930
	,,	,,	,,	,,	,,	10	3,600	900
Similar Gun	6·57	31·9	5	41	solid[1]	,,	3,700	740
Rifled 68-pounder Service Gun, Cast Iron, 95 cwt.	8·12	51·7	$6\frac{1}{2}$	90	$7\frac{1}{2}$	10	3,150	850
	,,	,,	8	,,	,,	,,	3,560	920
Rifled 32-pounder, Cast Iron, 95 cwt.	6·37	31·9	7	56	2	,,	3,700	955
Rifled 18-pounder, Cast Iron, 58 cwt.	5·29	22	$6\frac{1}{2}$	34	$1\frac{1}{4}$	,,	3,900	948
Smooth Bore 68-pounder Service Gun, Cast Iron, 95 cwt.	8·12	51·7	16	68	solid	0·30′	340	2,040
	,,	,,	,,	,,	,,	1	640	1,280
	,,	,,	,,	,,	,,	5	1,960	939
	,,	,,	,,	,,	,,	14	3,480	714
Armstrong Breech loader, Field Gun[2]	3	7	1.6oz	12	$\frac{3}{4}$ oz.	3	1,200	923
	,,	,,	,,	,,	..	5	1,820	900
	,,	,,	,,	,,	..	10	3,030	826
Ditto Large Gun	6	28·2	9	80	solid	10	3,900	-
Whitworth Breech loader, Field Gun	3	7	$1\frac{3}{4}$	12	solid	2	1,250	Initial
	,,	,,	,,	,,	,,	5	2,300	velocity
	,,	,,	,,	,,	,,	10	3,780	about
Ditto, Large Gun, Weight 80 cwt.	5·2	21	12	80	,,	5	2,600	1,300
	,,	,,	,,	,,	,,	7	3,490	feet per
	,,	,,	,,	,,	,,	10	4,400	second.

It would be seen from these figures, that up to about 10° elevation, the rifled cast-iron guns had at least as long a range as the wrought-iron breech-loaders with equal charges; and that at less than 5° elevation, the rifled service guns had a positive superiority in this respect. Nor was this all. The velocity with which the rifled service guns projected their shot, even with smaller charges of powder, was much greater than was the case with the breech-loaders. In the Official Reports of Mr. Britten's experiments, the time of flight of each shot was carefully recorded, so that there was no difficulty in ascertaining the mean velocities at the different

[1] Service round shot, prepared by Mr. Britten to suit rifled guns.
[2] *Vide* Range Tables in Horse Guards Manual, published by authority.

ranges. The mean velocity of his 49-lbs. shells, fired from the 32-pounder rifled service gun, was thus shown to be 1,120 feet per second, in a range of 1,600 yards; the 56-lbs. shell, with 7 lbs. of powder, had a mean velocity of 955 feet per second, in a range of 3,700 yards; and the 90-lbs. shell, 8 inches in diameter, with only 8 lbs. of powder, or one-eleventh of the weight of the projectile, had a mean velocity of 920 feet per second, in a range of 3,560 yards. When, therefore, it was stated, that the velocity of the Armstrong projectiles, on leaving the gun, with charges of one-eighth of the weight of the shot, was only 1,080 feet per second, and that of the Whitworth shot, with a charge of one-sixth, was under 1,300 feet per second, he thought it might safely be asserted, that the muzzle-loaders did more work with the power applied than the breech-loaders.

In order to show the great effect of the resistance of the air in diminishing the velocity of large bodies during flight, the mean velocities, at different ranges, of the 68-pounder service solid shot, with full service charges, were given in the Table. These figures were officially determined, from practice on board the 'Excellent' gunnery ship. It would be seen, that at 340 yards, the mean velocity of the service solid 68-pounder shot was 2,040 feet per second; but this mean speed fell off to 714 feet per second at the range of 3,480 yards. The same gun, when rifled, threw a 90-lbs. shell, 3,560 yards, with a mean velocity of 920 feet; it was therefore probable, that the initial velocity, in this case, must be very much more than was obtained by the breech-loaders. This was remarkable, when it was remembered, that the 8-inch shells had the resistance of the air upon 51 square inches, the sectional area of the shell; while the Armstrong and the Whitworth projectiles had a sectional area of only 28 and 21 square inches respectively, and were fired with much heavier charges. From these facts he inferred, that for horizontal fire up to 2,000 yards range, which was the service most required, his large-bore guns were in no respect inferior to the new small bores, while in many points they were far more serviceable.

There was one other point to which he would advert. The cost of an 8-inch cast-iron gun was about £100, while it was doubtful whether either of the new rifled breech-loaders of the same size, which had been so much spoken of, could be made for much less than £1,000. Then the projectiles for these breech-loaders would be costly. At present, he believed every shot for the Armstrong gun had first to be turned accurately cylindrical, then a considerable number of grooves had to be cut round it in order to hold on the lead, which had afterwards to be turned again. The shot for the Whitworth gun would be also very expensive, if, as was asserted, it had to be put into a planing-machine of

curious construction, and each of its six sides planed with the utmost nicety into the form of a screw, to fit the rifling. On the other hand, Mr. Britten's shells were plain castings, and would cost so little more than the common spherical shells, that the saving of powder, required to project them, would be an equivalent. This was a point of great importance, for the expense incurred in the cost of guns was trifling, in comparison with the cost of the projectiles to be thrown.

The system proposed by Mr. Britten would, in his opinion, not only enable the present service guns to be utilised, but he had shown, that the round shot and shell of all kinds, now in store, could be adapted, with great advantage, to suit the rifled service guns. The common 32-pounder round shot, when prepared with lead, so as to expand in the gun, and when fired at 10° elevation, with only half the usual service charge of powder, had nearly 1,000 yards longer range, than on the old system. The 32-pounder shot, when thus adapted, weighed about 41 lbs., and at 10° elevation, it attained a range of 3,750 yards, with 5 lbs. of powder; while the ordinary 32-pounder service shot, at the same elevation, only had a range of 2,800 yards, with 10 lbs. of powder. The cost of preparing the shot and shells with lead, in the way proposed, would be considerably less than the value of the powder saved; so that this advantage might be obtained, and a positive saving of expense be effected at the same time.

General Sir John Fox Burgoyne observed, that the subject before the Meeting, was one requiring the deep study of professional men, having a knowledge of the application of iron to bear different trials. His principal researches had been as to the practice with the gun after it was made. Some of the observations which had been offered did not quite accord with his views. It had been said, that it would scarcely be possible to make fortifications, to withstand the effects of these heavy guns. He thought, however, they would not affect fortifications in so great a degree. Supposing, for instance, a fortification to be thoroughly covered with a ditch and counterscarp, the escarp being thus entirely covered, the besiegers must get close to it before a breach could be made. Long-range guns might help to destroy the parapet somewhat earlier; but if the place was provided with casemates, it must be closed with, and then the old service guns were as good as the new rifled ordnance. In fact, they were better, as the velocity for the first 400 yards, or 500 yards was greater, although it was not maintained as in the rifled gun. These guns would also be available for defence, as well as offence. A remark had been made, as to the comparatively small value of long ranges, such as the one of between five miles and six miles obtained by Sir William Armstrong, and Mr. Whitworth. That great length of range was, perhaps, not of so

much importance in itself, but it was an indication of other qualities. It was a proof of superior accuracy and greater power of penetration. It likewise gave the power of firing at lower angles of elevation, which was of great value. The Armstrong and the Whitworth guns were very perfect, light, of beautiful workmanship, and of great strength. If better could be devised, it ought, by all means, to be done; and he hoped that the Members of this Institution would assist in bringing about still greater improvements. With regard to the expense of the manufacture of the Whitworth shot, he might state, on the authority of that gentleman, that the additional expense in shaping was not more than a penny per shot.

Mr. JOHN ANDERSON said, he would endeavour to confine himself to the ostensible object of the Paper,—the best principle of constructing a gun, so as to afford the artillerist the full development of the gunpowder used to throw the projectile. The Author argued, that the system of constructing a gun by binding it round with wire, was the true one. He fully coincided in that opinion, on theoretical grounds; but at the same time, he agreed with the remarks which had been made, as to the difficulty of applying that material. The great objection to the wire system was, that it had no end-hold, and thus it could not be depended upon, for forming a good breech, and producing a substantial and thoroughly good serviceable gun. He believed that Fig. 18, (page 318,) represented the construction of a gun, which the Author thought would be most likely to secure the object upon that principle. While agreeing with the principle, Mr. Anderson thought there were many better ways of carrying it out. Before stating his views on this point, however, he would allude briefly to what had been said in favour of cast iron. He did not think the great results expected by the artillerist, would be secured by the use of a homogeneous material like cast iron. It was most uncertain in character; one day a gun stood well, while on another day, it burst, without giving any warning, even when the same amount of care had been taken by the founder. Great expectations had been raised, of late years, by the system of strengthening cast iron by the employment of wrought-iron hoops. Without entering into the question of the priority of invention, he might say, that great results had already been obtained by the use of wrought iron in that manner. Still, taking into consideration the risk of failure, which experiments made within the last few days showed was possible, together with the expense, he thought another direction held out a better prospect of success. A few years ago, it was believed, that the proper gun would be obtained by forging. In 1854, when Mr. Nasmyth was at work, the country expected great results,

The end of that gun might be said to have been a national disappointment. Since then, there had been the Liverpool gun, a monster mortar, which was referred to in the Paper. It was a magnificent forging,—the finest he had ever seen,—yet it was not a perfect gun. The bore of that gun would never have passed the proof of the artillerist. There were defects in it, and that would always be, more, or less, the case, in the heart of all such large structures when forged. At the present moment, there were at Woolwich some apparently very fine forgings, which were defective, owing to fissures at the core, and more especially, in the chamber at the breech. Therefore, he did not think the good gun, which all were aiming at, would be obtained by the system of forging. So far as his own experience went, the best result was to be obtained by building up, on the principle of hooping. When he spoke of the best result, he did not mean the mere conditions of supplying the wants of the artillerist, but he had also in view the important question of cost. In reference to the cost of Sir William Armstrong's gun, which had been alluded to, he might state, that the 12-pounder gun, complete, was now being made at Woolwich at a cost of under £90; this was about one half the cost of the old 12-pounder brass gun, the value of which was £175. 10*s*. When it was remembered, that in the one case the material cost about £19 per ton, and in the other about £125 per ton, together with the great difference in weight, there was a large margin to work upon. Having had considerable experience in this question for many years, he might say, that it appeared to him, that the gun of the future must be a built structure. He was not now prepared to say precisely how the detail of the structure was to be carried out, whether with a wrought-iron, or a steel lining to the bore, supported with a covering of wrought iron under compression; but he maintained that it must be a built gun. From the readiness with which wrought iron could be worked into the handy form of a bar of any section, by means of the rolls of the iron-maker, and the equal facility with which this bar might be wound upon a mandril, in a sort of lathe, and then welded into a tube, or drum, a degree of cheapness, combined with extraordinary strength, was secured, in a manner not equalled by any other method yet introduced into the iron manufacture. When the system of tools was adapted to manipulate the material into the right form, the greatest amount of strength would be obtained by the built gun, consisting of such hoops, or drums, shrunk, or forced together. This was the principle, which Sir William Armstrong and others were now working out, and it appeared to be that which would afford the greatest strength, and would constitute the cheapest description of structure for guns. He thought, that the cost of obtaining

this peculiarity of construction had been over-rated in the Paper. In olden times, there was a difficulty in working to the $\frac{1}{16}$th of an inch; but the $\frac{1}{1000}$th of an inch was now measured with as much ease as was formerly the case with the $\frac{1}{16}$th, or $\frac{1}{32}$nd of an inch. Although it might not be possible to bore to the $\frac{1}{1000}$th of an inch, yet by means of turning, a gun could be most accurately and economically put together. He had said that the wire system was defective, inasmuch as there was no end-hold. Looking at Fig. 18, (page 318,) it would be seen, that a band was passed round the breech. To his mind, that was not the right principle of construction; nor did he think that was the kind of gun which was likely to come into use.

In reference to the complaint which had been made in the Paper, as to the treatment of the Author's invention by the Ordnance Select Committee, Mr. Anderson, having had the honour of being a member of the Committee at the time, would like to make a few remarks. He would ask whether any ten independent men, having undertaken the responsibility of recommending a gun which involved the expenditure of hundreds of thousands of pounds, would not even now hesitate, before recommending the wire system of construction? He thought there were few persons who, having to make a selection, would advise the construction of a gun upon the wire system, after knowing what Sir William Armstrong and Mr. Whitworth had done, with built wrought-iron and steel guns, on the principle of hoops shrunk, or forced on.

Mr. Clay said, that having designed and manufactured the large gun which had been made at the Mersey Company's Works, he might, perhaps, be permitted to say a few words on this subject. The Author had called attention to the difference in the tensile strength of the material forming the inside and the outside of large forged ordnance, and had observed, that the same thing had been noticed in the gun made at the Mersey Works. Moreover, it had been stated, that large masses of metal, forged in that way, must be subject to inequalities of structure, which rendered them unfit for heavy ordnance; and that the gun in question was, on that account, untrustworthy. Now the gun was tried at Liverpool, before it was delivered to the Government, and was then pronounced by the officers from Woolwich to be fit for Her Majesty's service. After that, it was subjected, at Shoeburyness, to nearly double the charges which were used at Liverpool. Hundreds of rounds had been fired from that gun, yet it was still as good as on the day it was first made. With regard to the systems of hooping guns, and of covering them with wire in a state of tension, one thing had escaped notice; that was, the variation in the amount of expansion and contraction in different qualities of iron. It had been stated, that an error of $\frac{1}{500}$th of an inch would cause a

serious difference, in regard to the tensile strain which would be brought upon the several parts. Now he believed it would be found, if careful experiments were made, that different descriptions of iron would vary more than $\frac{1}{500}$th part of an inch, in the rate of expansion and contraction. He knew that iron and steel differed much in their expansion and contraction, and he thought it would be found to be the case with iron generally, according as the crystallized, or fibrous structure predominated. He considered it was a dangerous system to pursue, to build up guns with concentric hoops, as no dependence could be placed upon the degree of initial tension with which they were shrunk on. Some remarks had been made as to the liability of hydraulic presses to burst. He had made many large cylinders, and was not aware of one having so failed. The presses used in the manufacture of lead pipes were, perhaps, subjected to the severest test to which cylinders could be exposed. It had been said, that the process of forging was not the proper one for the manufacture of ordnance. It so happened, that at the present time, he had before the Select Committee, a plan to make ordnance by a different method. He was not at liberty to describe the method, but he might say, generally, it was by the rolling process. In several guns made in that way, he had not found a single defect, either in the bore, or in any other part. He had recently fired, in the presence of a number of Artillery Officers, twenty-two balls, with a cylinder projecting 12 inches from the muzzle, with $1\frac{1}{2}$ lb. of powder, out of an iron gun with a bore of $2\frac{1}{2}$ inches. A steel gun was also tried in the same manner. He considered that the manufacture of ordnance was still in its infancy; but he trusted, that as the public mind was now directed to that particular science, important improvements would be introduced.

Mr. Vignoles observed,—through the Secretary,—that the gunpowder experiments of his grandfather, the late Dr. Charles Hutton, had been very carefully made and often repeated. The calculations and deductions from these experiments, showed results equal to a pressure of 17 tons per square inch on the metal of the gun. This had appeared, to the President, when first mentioned, as very high, but he had since observed, that his own calculations brought out even 20 tons. Mr. Vignoles remarked, that from data recorded, his calculations induced the conviction, that the pressure was often nearer to 30 tons, than to 20 tons on the square inch. On mentioning the subject to Professor Airy, (Hon. M. Inst. C.E.,) that distinguished mathematician and philosopher expressed the opinion, that under certain circumstances, the force of gunpowder was much greater than had been stated. Mr. Vignoles thought, that attention should at once be directed to this point, of so much importance, and so easy to be determined, in order to put the matter beyond dispute; and thus the principles on which this enormous pressure was to be counteracted, would be clear of all doubt.

Mr. HADDAN stated, that his operations had been limited to the existing service gun. He started with this axiom, that for a cast-iron gun the rifle twist should be as slow as possible, so as to establish only such an amount of rotation of the projectile, as would insure its travelling point foremost throughout its flight, and that any greater extent of rotation was useless. Another essential point was, that the rifling should weaken the gun as little as possible. He assumed, that if the rifle cuts, or grooves, were angular, or square, they would have the same effect, as nicking a bar of iron intended to be broken; whilst broad and shallow grooves, or cuts, would not destroy the elasticity of the gun. An ordinary 68-pounder cast-iron gun had stood firing, with shells 115 lbs. in weight, and considerable charges of powder, without bursting. He believed the plans of Mr. Whitworth and Sir W. Armstrong were inapplicable to cast-iron guns, and hence resort was had to built guns of malleable metal. The large cast-iron guns which had been bored on the Whitworth system, and the calibre of which was small, had burst, owing, as Mr. Haddan believed, to the quickness of the rifle twist. He had fired a shell, (of which a specimen was exhibited,) weighing 90 lbs., with the rifle twist, only about one turn in 40 feet, whilst the Whitworth 3-pounder had a twist of one turn in 40 inches. The Government report upon the experiments with a service 68-pounder cast-iron gun, rifled upon the principle he had adopted, showed that he had obtained equal ranges, charge for charge, to the Armstrong gun. He believed, that the length of range depended upon the charge of powder used; and on that ground, he invited comparison with the results of Mr. Whitworth's and Sir W. Armstrong's experiments. In the generality of cases, he understood the Armstrong gun had been tested with a charge of powder equal to one-eighth the weight of the projectile; whilst in Mr. Whitworth's experiments the charge of powder appeared to be only one-fifth the weight of the projectile. Again, in considering the flight of the projectile, it was important to know whether it was hollow, or solid. The large shell weighing 90 lbs., which he exhibited, was 8 inches in diameter, and was made to contain a bursting charge of nearly 6 lbs. of powder. Mr. Whitworth's 90-lbs. shot was solid and was only about 5 inches in diameter. With the same charge, therefore, Mr. Whitworth's would necessarily have a longer range.

In a letter to "The Times,"[1] Sir W. Armstrong said:—

"With respect to ranges exceeding 2,000 yards, I may state, that on previous occasions the gun had been tried up to 3,000

[1] *Vide* "The Times," January 3rd, 1857: (page 5). Reprinted in "The Mechanics' Magazine," April 22nd, 1859: (page 262).

yards,—a distance which was reached with an elevation of 11°,—and the usual charge of 10 ounces of powder, or one-eighth the weight of the projectile. By augmenting the charge the range is increased, but the accuracy is impaired, and I therefore adhere to the 10-ounce charge, which gives ample penetration, as the experiments at the butt will testify."

The shells adopted by Mr. Haddan were fit for use, without any manipulation, after they came from the founder's hands; and he could obtain a long range, with a small charge of powder, as compared with the weight of the projectile, and as he believed, at a very small cost. In corroboration of this remark, he would state, that the two shells exhibited, had been cast at the Royal Foundry, at Woolwich, and Mr. Davison had informed him those shells, fit for service, would not cost more than the ordinary service shells, or not exceeding £5. 6*s*. per ton. A common service gun, rifled for him by Messrs. Napier, York Road, Lambeth, was tried at Shoeburyness on the 23rd of February, 1859. From the Government Report it would be seen, that the charge was 10 lbs., the elevation 10°, and the range 2,900 yards. The projectiles weighed on an average 90 lbs., and were capable of containing about 5½ lbs. of powder. Both the deflection and the range were very uniform. If, therefore, cast-iron guns were not all that was desired, yet for many practical purposes, it was evident they might be made largely available as rifled ordnance. He thought it would be generally agreed, that before the Government incurred the serious expense of making wrought-iron guns of large size, it should be placed beyond doubt, that the present service guns were not available. At present there was no proof, that cast-iron guns could not be used. A statement had been made, that every cast-iron gun that had been rifled, had failed, but that was utterly untrue. Mr. Britten had rifled several service guns, and not one of them had burst. The guns experimented upon by Captain Scott, R.N., Mr. Jefferies, and others, had not burst, nor had the 68-pounder, rifled by himself, been injured.

Referring to the employment of lead, in the construction of the projectile, he said that he had always thought it objectionable, and therefore, did not make use of it. He preferred a wad of wood, or other material, and placed it at the conical back of the projectile. The first blow from the explosion of the powder drove the wad tight round the projectile, and caused it to expand so as to fit the gun. There was thus no loss from windage. This projectile possessed all the advantages of the lead-coated one, and in addition, the wad was cheaper and cleansed the gun; there was no difficulty as to transport, and it was immaterial how rusty either the guns, or the shells might be. By means of the broad shallow grooves, or cuts, he did not materially weaken the gun, and by

giving to the rifling a slow twist, of only about one turn in 40 feet, there was little strain on the gun when discharged, and therefore, little, or no tendency to burst it. He had lately had two 32-pounder service guns rifled by Messrs. Napier. They had been tested with 56-lbs. shots and a charge of 7 lbs. of powder, and neither of them had burst.

When his proposition was brought before the Government authorities, there were already eighteen, or twenty different plans for rifling the service guns. It was suggested, that each should rifle a gun upon his own principle, so as to prove practically which method would answer best. That appeared to be a perfectly fair mode of proceeding. Whether the experiments had been carried out by the others he could not say; but he understood, that Sir William Armstrong had made two attempts with service guns, both of which had burst, and that Mr. Whitworth had been equally unsuccessful. Mr. Haddan was prepared to take his two rifled 32-pounder service guns, with the shells, which required no labour to finish after they came from the founder, and to fire them against those of Sir W. Armstrong and Mr. Whitworth, with the same relative charge of powder, and thus to let the results show which system of rifling was the best.

Mr. Bramwell said the Author had stated, that it was a bad practice to cast guns solid; and in Fig. 1, (page 290,) he showed the assumed lines of contraction of the metal in the interior of a gun so cast. Every practical man must agree, that a solid casting was objectionable, and that a gun would be stronger if it were cast hollow, so that the contraction should commence simultaneously in the inside and at the exterior. No doubt, formerly, from the want of the appliances of the present day, difficulties were experienced, which caused the plan of casting guns hollow to be abandoned, and they were, therefore, made solid. He had upon a previous occasion mentioned that, in the American service, Lieutenant Rodman had introduced the principle of casting guns hollow. To obtain the full benefit from the interior cooling before the outside, water was passed through the core of the gun, equal to sixty times the weight of the casting; the operation being continued for seventy hours, and the outside being kept heated by fires. The result of comparative experiments with a solid and with a hollow gun, both run from the same furnace, and made from precisely the same metal, was that the 8-inch gun, cast solid, burst at the seventy-third discharge, whilst the 8-inch gun, cast hollow, with water passed through the core, endured fifteen hundred discharges, and did not burst. He thought that went a great way to show, that the principle of casting a gun solid was wrong; and that when it was cast hollow, the metal was in the best condition to resist the strains put upon it. In the Paper it was stated, that the tensile strength

of cast iron, in a gun cast solid and then bored out, was 8 tons to the square inch, at the outside of the gun, and 4 tons to the square inch, at the side of the bore. In the solid gun cast by Lieutenant Rodman, a sample cut out near the trunnion showed a tensile strength of 44,000 lbs. for the outside, and 31,000 lbs. for the inside. That also was another indication, that a gun ought to be cast hollow, if cast iron was used at all. In the account of the experiments made by the American Government, it was stated, that guns had been tried which had been kept a long time after being cast, and before being tested. A gun which had been so kept for six years, endured eight hundred discharges before it burst; while another gun endured two thousand five hundred and eighty-two discharges, and did not burst. Guns of the same description, tried thirty days after casting, burst, one at the eighty-fourth, and the other at the seventy-second discharge. This result showed, it was not impossible, that the superior manner in which guns cast some years ago, but recently used, had stood their work, was due to their having been cast a long time, rather than, as was commonly supposed, to their being of a better quality of metal; and to the strains that existed in them, from unequal contraction, when originally cast, having ceased, while the strains in the new castings were still exerting a prejudicial effect. It was proved, in the case of the two guns to which he had alluded, that the gun which burst after eight hundred discharges had a tensile strength of 23,000 lbs., and that which endured upwards of two thousand five hundred discharges, without bursting, had a tensile strength of 29,000 lbs. to the square inch. Of the guns which were tested thirty days after being cast, the one had a tensile strength of 27,000 lbs., and the other a tensile strength of 37,000 lbs. per square inch of section. Both these recently cast guns endured a less number of rounds, than those which had been cast some years, although the metal of these latter was much weaker than that of the former. It was a general opinion, that castings ought not to be put to work too soon after being made, and in tilting ingots of steel, it was preferred that they should stand some days after being cast, before being subjected to the tilt hammer. It had been the practice to keep wire for some time between the 'drawings,' in order that its particles might recover their relative condition, before being again subjected to strain. He, therefore, considered there was a fair prospect, that if good cast iron was used, and guns were cast hollow and kept some time, or even if cast solid and kept, cast-iron guns might be made successfully. As to the tensile strength of cast iron, he had a sample, which was broken at the testing machine at Woolwich, that bore 19½ tons to the square inch of section, before it gave way. He thought that 8 tons was too low an estimate to take for cast iron, in a gun.

There was another point which had been rather overlooked. The explosive force of gunpowder had been variously estimated, as amounting to from 7 tons to 70 tons per square inch. It had also been stated, that in a cast-iron gun, the average strength available to resist the pressure that was brought to bear upon it, could not be taken at more than 2½ tons to the square inch. It was quite clear, that these statements of the force of powder and of the strength of iron could not be reconciled. But one thing had been neglected, the area of the section of the gun which bore the strain. If a gun of infinite length were loaded, the metal which bore the strain would be only the metal at the sides of the gun, and all the discussion had been based on this assumption. If that metal were equal on each side to the bore of the gun, it followed that for every inch subjected to the pressure of the gunpowder, there were two inches of iron in tension, or of metal to be burst through. If there were, as in a 68-pounder with a service-charge, a length of about 15 inches, where the greatest pressure was exerted, there would be the same metal at the sides to burst through, and in addition, a portion of the annular section of the gun, making 3½ inches instead of 2 inches of metal to be broken through, for each inch of area pressed on. This appeared to be the reason why a comparatively weak metal was capable of enduring a pressure, which, at first sight, it seemed unequal to bear. Regarding the metal which had to resist the strain in this way, decreased windage might operate favourably; for although it might increase the pressure per square inch in the gun, yet nearly the whole power of the powder was employed in propelling the projectile, therefore the amount was diminished, and the part subjected to pressure was shorter; and thus the annular section to be torn through, bore a greater ratio to the area pressed, than it would with a longer charge. If this view was correct, it was an argument against building a gun with hoops, and still more against the ingenious plan proposed by the Author, of covering the gun with wire, which only gave radial strength. He thought, however, that the plan of binding with wire, enabled an accuracy of strain to be obtained, which could not be obtained with hoops. The varying qualities of the metal and the difficulty of shrinking on hoops to the $\frac{1}{300}$th part of an inch, which was said to be necessary to insure success, were insuperable objections to that system. He did not agree in the opinion which had been expressed, that although a barrel covered with wire might be made sound, yet a strong breech could not be formed with wire. In some experiments he had made, in conjunction with Mr. E. A. Cowper, (M. Inst. C.E.,) with steel wire of No. 22 music-gauge, in which, it should be remembered that the numbers ran in the reverse direction to wire gauge, the tensile power was found to be as high as 142 tons per square inch. There

was another matter to be borne in mind. Assuming that hooped guns could be made with the accuracy shown in Fig. 5, (page 298,) when the explosion took place, the whole gun was in equal tension; but in time, the hoops in tension would stretch, and those in compression would give way. Therefore lapse of time, as regarded those guns, would do injury instead of good, as was the case with cast-iron guns.

Captain SCOTT, R.N., believed, that the ordinary cast-iron service gun would do all that could be fairly required, and would stand rifling, if too heavy shot were not attempted to be fired, and too sharp a turn were not given to the rifling. The shot he used were plain castings. In making them, he had endeavoured to obtain the form for permitting the greatest velocity through the air, and at the same time, for keeping up the rotation as perfectly as possible. His shot were cast so as to bear on three groves in the gun, and were so shaped as to carry round little, or no air. In this respect they had a great advantage over polygonal and lead-coated shot, with which a large quantity of air must be carried round in rotating. This defect he had endeavoured to avoid, by deviating as little as possible from a cylindrical form. When that, or a circular form was not adopted, as, for example, if the shot was polygonal, a greater amount of initial rotation was required, than if the shot were of a figure adapted to keep up the rotatory movement. Hence, those who had tried the polygonal form, or who had fired a lead-coated shot out of a many-grooved gun, had been obliged to give a greater amount of rotation to the shot, than would have been necessary with fewer projections. His plan had also these advantages. The cast shot could be cheaply and easily made in any number, while there was a difficulty in the manufacture of compound shot, and in time of war, he did not see how they could be carried, in large quantities, without damage. On the other hand, the common cast-iron shot could be carried in bulk, and be stacked in the open air, without injury. The guns rifled for elongated projectiles by Mr. Haddan, Mr. Britten, and himself, would also fire round shot, and he felt certain that round shot would always finish naval actions. The elongated shot had this special disadvantage: it would not, like a round ball, at once run home in charging the gun; besides which, at close quarters, no projectile was more destructive than the round shot. A remark had been made as to the greater initial velocity of round shot, and the greater injury caused by them to parapets, than by any elongated shot which had yet been tried. He considered, therefore, that in rifling the present cast-iron guns, it should be done in such a way as to admit of round shot being fired, without damaging the grooving, and yet with accuracy. There seemed to be a general feeling against the

use of cast-iron guns, from their fancied insecurity. It had been said, that cast-iron guns were almost as brittle as glass, and that they would not safely stand firing. He was astonished to hear such statements, for after twenty years' experience, as a gunnery officer, he had never seen an accident from the bursting of a gun. He believed that in those instances in which guns had burst, they had done so either through extremely careless loading, or else from being exposed to the air for years, and becoming honey-combed by oxidation. He did not agree with the statement, that a gun required a long period of rest to gain strength. He thought a few months' rest, after casting, might be necessary for the particles to set; but if a gun was left longer exposed to oxidation, it became weaker, from the moment oxidation commenced.

With regard to the mode in which new guns should be cast, he considered there was a great advantage in casting them with a core, because then the inside skin of the gun would be strong and hard, and the metal generally, from its decreased thickness, would be more homogeneous. All that was necessary to convert the present gun boxes, for casting with a core, was to plane their tops, and to have the core spindle made to pass through a properly-fitted cover, so as to expand in guides when heated by the hot metal. With guns thus cast, the wearing of the bore, by the elongated ball, would be very small. Even with the ordinary 32-pounder gun he had tried at Shoeburyness, which was cast solid, and therefore, had a comparatively soft bore, he could scarcely detect a scratch upon the rifling, after firing his cast-iron elongated shot. He was astonished to find that the friction, and consequently, the strain due to the rifling, was so little. With respect to the mode of casting iron guns, he believed another great improvement might be effected. At present, from being cast solid, they were made with a degree of hardness which was injurious to tenacity, in order that the centre of the gun might not be worn away by the rubbing of the shot. Some of the guns cast at Woolwich, which were known to be too hard, were not tested in the first instance. On being recently proved, they burst as was expected; but those which had been made subsequently, stood the highest proof-charge perfectly. Nothing definite could be deduced from the bursting of a few cast-iron guns, under such circumstances. The factory at Woolwich was in its infancy, when the hard guns were cast, and only about two hundred guns had been made before the establishment was broken up. All new factories were liable to make similar mistakes. The failure in this case was owing, in part, to the iron used, which was of inferior quality and of extreme hardness; but when better iron was substituted, good guns were made. After guns were cast, they were frequently subjected to a great deal of rough treatment. The longer a gun was allowed to cool, in the position in which it was cast,

the better; and if it were cast with a core, toughness of the mass might be attained, with sufficient hardness for the rifle grooves. The bore, after casting, should be carefully made straight, and be smoothed, without taking away much of the skin. As to the outer part, the gun, when it came from the foundry, was at present turned down; so that the skin, or that part of the gun which would perform all that the wrought-iron bands were expected to accomplish, —keep the iron in its natural and perfect state of compression,—was taken off. The gun was thus not only much weakened, but was also rendered very liable to rust, which, after long exposure, destroyed the tenacity of the metal. Not content, however, with merely removing the skin from the gun, it was taken off unequally, leaving rings and patches, and these inequalities checked the proper vibration and expansion of the particles of the metal on discharge. The whole force of the explosion, and the rapid rubbing of the shot, caused a strong vibration through the gun. This vibration was greatest after the ball had moved, and before it had acquired sufficient velocity to compensate for the augmented volume and increased compression of the gunpowder gases. In the ordinary service gun there was a projection round the muzzle, and another round the breech, while at the trunnions there was a great patch, which checked the expansion and vibration.

Another disadvantage of the projection at the muzzle was, that on board ship, it caused the loss of 1° in elevation and 1° in depression, as well as 1° in training right and left. Now that long ranges were demanded, to cut off 1° of elevation and depression, for the sake of retaining the useless muzzle swell, did seem absurd. He mentioned these matters merely to show, that this question had not yet been thoroughly examined. No Select Committee had sufficient time to go into the details of the wide and important subject of the improvement of cast-iron ordnance; there was such a pressure of other business upon their hands, that it appeared to be impossible.

Captain Boxer, R.A., said, the principal subject dealt with, in the Paper, referred to the construction of artillery, in allusion to which, the Author said, this was a question, with which, in his opinion, no one was more able to deal, than the Civil Engineer of the present day. Captain Boxer could not concur in that opinion. Although one particular Civil Engineer might be better fitted to deal effectually with a subject of this sort, than one particular Officer of the Royal Artillery, that was a personal question; but it did not affect the general proposition. It must be borne in mind, that it was not only the business and the duty of the artillery officer to make himself thoroughly acquainted with the properties of various materials, including metals, woods, and other substances; but he was also bound to investigate the subject, with

reference to the peculiar action and effect of fired gunpowder, under various conditions, upon those materials. He thought it would be admitted, that those specialties could not be considered as an essential part of the professional acquirements of the Civil Engineer.

The Author had not been guilty of flattery in speaking of the Ordnance Select Committee. Having been a member of that Committee at the time this invention was referred to it, he might state, in answer to the remarks which had been made, that if it was merely intended to convey, that the proposal was not accepted, or rather was not recommended for adoption, then the Author was quite correct; because out of a hundred plans which were laid before the Committee, possibly not one was recommended for adoption. But if it was desired that the inference should be drawn, that the subject which was brought before the Government, and referred to the Select Committee, was not properly dealt with, or duly considered, but was rejected without due investigation, that was a matter of opinion, which was open to fair argument. Captain Boxer did not, however, think any good would result from making insinuations against the Committee; nor did he think it right to make remarks of this sort, when the Committee had no opportunity of meeting the objections.

The Author stated he had ascertained, from his own experiments, that the strength of gunpowder was equivalent to 17 tons per square inch. Not being aware of the method adopted for determining this pressure, Captain Boxer could not say whether there was any error in the manner of making the experiments, or in the deductions from the trials. But he might observe, that the subject of the explosive force of gunpowder had engaged the attention of the most eminent philosophers; and notwithstanding this,—notwithstanding the most careful calculations, involving the highest order of mathematics, made by those practically acquainted with the subject, no satisfactory results had yet been obtained. In considering the force of gunpowder, there were two main points to be regarded. First, there was a certain definite pressure, which might be termed the statical force, or the force which was effectual in giving motion to the projectile in the bore of the gun. Secondly, there was a percussive force, in addition to that already mentioned, and of a different nature from it, which principally tended to cause destruction to the material of the gun. With regard to the first,—the initial force, or pressure of gas,—although the average pressure which was exerted upon the bore of the gun, during the passage of the shot through the bore, might be determined, by finding out the initial velocity of a shot of a certain weight, when projected from a gun of a known length; yet when it was attempted to determine the initial force, or pressure exerted by the gases

when first generated, and when filling that portion of the bore originally occupied by the charge of powder, the question would be found to be involved in the greatest possible difficulty. He had never been able to satisfy himself, that any right solution had been arrived at; and he thought the wide difference of opinion, which existed upon the subject, confirmed the view he had expressed. With reference to the second point, namely, the percussive force of the powder which was exerted, principally tending to cause rupture, over and above the statical pressure, and which did little towards giving motion to the shot, he would observe that, upon the explosion of gunpowder, there was, no doubt, a force exerted similar in character to that of percussion, or an effect was produced like that caused by a body in motion coming into contact with a body at rest. This force, which was generated at the time of the explosion, could not be measured by, or be compared with, any statical pressure, and he believed it was owing to this force not being taken into account, or to erroneous ideas of its nature, that so much discrepancy of opinion existed.

It appeared to be the fashion, at present, to condemn cast iron as a material for guns. He thought it was premature to do so. First, it must be remembered, that cast iron had done good service, and had, for many years, been found a valuable material for guns. It should not, then, be condemned without careful investigation. No doubt, since the introduction of the system of rifling, and of large calibre for firing solid shot, the strain upon the gun had been much increased; that was to say, the strain in those guns was greater than in ordnance of smaller calibre formerly used. It was clear then, that if cast iron was employed, a stronger quality of metal was required, than was before found to answer. He was of opinion, however, that by careful investigation, a material might be obtained, and a mode of treatment of the metal might be discovered, which would enable cast iron to be used, with advantage, for rifled guns constructed upon true principles. Cast-iron guns had been made, possessing an enormous amount of enduring power; but it was essential to insure uniformity in this respect. He believed that by close investigation, a mixture of cast iron might be obtained, possessing all the necessary properties of a good gun metal. He thought, for these reasons, that cast iron ought not to be altogether condemned, and he was of opinion, that at some future time, cast iron would again be brought into use for artillery. At the same time it was not clear, that cast steel, or some preparation of cast iron, might not answer the purpose better than the systems of hooping, or of covering with wire, or even of building up, as in the manufacture of Sir William Armstrong's guns.

Mr. Longridge remarked, that he had not said anything dero-

gatory to the Ordnance Select Committee. He had merely stated facts, and if they conveyed the impression just intimated, he regretted it, but he was not answerable for it.

Captain BLAKELY, R.A., remarked, that as the name of Lieut. Rodman had been mentioned, it might interest the Meeting to know, that a gun had been lately cast on a hollow core, with perfect success, by that distinguished officer, although the weight of the gun was 39 tons. He might add, that Lieut. Rodman's plan was another application of the principle brought forward by the Author of the Paper, and had first been proposed in the United States, in 1851.

Sir CHARLES FOX said, some years ago he expressed the opinion, that it was important to arrive at that condition of things in a gun, which should, when an explosion took place, make available the whole thickness of the gun. This, he believed, had never, hitherto, been effected. At one time, he thought he had discovered a mode of doing it; but at the present moment, he confessed he saw great difficulties in arriving at such a result. If a gun was built in separate parts, without being cemented together by soldering, or welding, he thought it would at some time, and that not a distant one, prove to be of no use. Although guns might be made by using a tube for the internal portion, turning the outside to an accurate cone, and then, by hydraulic power, pressing on it, with proper degrees of force, various layers of hollow cylinders, so as to insure every part having its proper initial strain, still he thought a very little use of that gun would so change the condition of its parts, as to destroy all the advantages of so expensive a mode of construction. The difficulty of making a gun, by encircling it with wire, especially in forming the breech, was so well known, that it was unnecessary for him to refer to it. He believed it would, eventually, be found, that the best gun could be constructed with some extremely dense and homogeneous alloy, cast and used without being drawn under the hammer. If a gun was made of an alloy possessing very great density, the detonating force of the powder would be resisted by a greater quantity of the metal employed, than it could be by making use of one with greater elasticity. He thought, therefore, the best guns would be made of iron mixed with some other metals, such as wolfram and titanium, so as to insure the greatest strength and density. Mr. Mushet had obtained great density, by mixing with iron a small percentage of wolfram, and great strength by the use of titanium. Therefore, he was inclined to believe, that guns cast of the densest alloys would have greater effect, in proportion to their thickness, than could be obtained by any complicated and expensive mode of construction.

Mr. F. A. Abel said, the discussion seemed to have regard chiefly to mechanical details,—to the manufacture of the metal and its conversion into the form most suitable to withstand repeated heavy strains. As the Chemist to the War Department, any observations he might make would refer, more particularly, to the comparative chemical qualities of the materials for cannon. He had heard the remarks which had been made, both by Engineers and by Artillery Officers, with reference to the best system of constructing guns, and the materials of which they should be manufactured. He agreed, to some extent, both with the advocates, and with the opponents of cast iron. He did not think, however, that cast iron could be considered as altogether untrustworthy, as a material for rifled cannon. He entertained this opinion, because the chemical examination of a large number of samples of cast iron, from different sources, either as obtained from the blast furnace, or after repeated re-meltings, had led him to the conclusion, that the uniformity of this material was, to a great extent, under control. He had examined specimens obtained from some of the best ironworks, and on comparing with them samples made, at intervals of two, or three years, at the same works, he found them, from a chemical point of view, almost identical in their nature. There might be a variation in the density, and other physical properties, resulting from the temperature at which the metal was cast, and from other circumstances, but the regulation of such differences was under the control of founders and engineers. If, therefore, it was found that cast iron might, with proper attention to its manufacture, be made almost perfectly uniform, some faith ought to be placed in that material. At the same time, the important results obtained by the further treatment of cast iron, should not be lost sight of. By progressive decarbonisation, it might be made to approach to perfect steel in its nature, or to acquire the characteristics of malleable iron. Such conversions could, a few years ago, only be carried out upon a small scale, or by most laborious processes; now they could be effected upon a very large scale, so that masses of the products, of great size, could be produced. Amongst others, Mr. Bessemer had obtained results which should not be passed over. He thought they might prove most important, particularly when it was remembered what had already been done in this direction, by Mr. Krüpp, in Prussia. A gun of cast steel manufactured at his works at Essen, had been tested in this country, and it was found almost impossible to burst it. That gun was cast in one mass, and the system of manufacture had been pursued in Prussia with such success, that rifled field-guns were now being constructed in that country, exclusively of this material, with every expectation that they would prove equal to the guns made in France and in England. He thought the results already obtained with those

materials should not be neglected; but that the proper authorities should embrace, as far as possible, the opportunity afforded to try fairly what guns, of that material, would do, as compared with guns of cast iron and with built guns of wrought iron. It appeared to him, that if a material suitable for the construction of a light and durable gun could be obtained in one mass, a vast number of possible sources of failure would be avoided. Nor would reliance have to be placed upon a number of details, which, although determined on the most correct theoretical principles, could only be perfectly carried into practice with great difficulty. It was questionable, in his opinion, how far the various suggestions relative to the construction of built guns should be entertained, until the question of the possible construction of durable rifle guns, in one mass, had been fully and fairly gone into. He anticipated that materials such as cast steel, or homogeneous iron, cast in large masses, must, independently of cost, furnish better results than other materials which had been proposed, on account of their greater uniformity.

He stated, in reply to an inquiry, that he had been induced to make some experiments upon the combinations of phosphorus with copper; and had found that, by the introduction of a small proportion of that substance, say from 2 to 4 per cent. of phosphorus into copper, a metal was produced, remarkable for its density and tenacity, and superior in every respect to ordinary gun metal, (the alloy of copper and tin known by that name). He believed the average strain borne by gun metal might be represented by 31,000 lbs. upon the square inch; whilst the material obtained by adding phosphorus to copper, bore a strain of from 48,000 lbs. to 50,000 lbs. But the increased tenacity was not the only beneficial result obtained by this treatment of copper. The material was uniform throughout, which was scarcely ever the case with gun metal. The experiments alluded to were merely preliminary, and had been, to a certain extent checked, by the improvements since introduced in the construction of field guns, which had led to a discontinuance of the employment of gun metal.

Mr. E. A. Cowper explained the construction of the Swedish percussion shell, which had not yet been referred to. It was an ordinary round shell, and in the interior there was a small percussion ball, having tubes to be furnished with caps. The end of one of the tubes, which pointed towards the breech, had no cap on it; so that the blow, or shock, caused by the powder when fired, did not explode the shell. But as soon as the shell came in contact with any object, the caps caused the shell to explode by the percussive action. That was a good thing in itself, but when rifled guns were used, it was sufficient to put one cap at the end of the projectile. An elastic ring, or wad, well tallowed, was fitted behind the shell, so that when the blast of powder took place, the ring was

forced between the shell and the gun, thus saving windage, and insuring greater accuracy in firing. By this system the charge of powder could be reduced, and the rattling, or rebounding of the shell from side to side of the gun, was prevented.

Some of the more marked distinctions, which had been pointed out, between the different plans of guns, alluded to in the Paper, or in the discussion, might be thus tabulated :—

Designation.	Gun.		Projectile.		Windage.		Strain due to Projectile.	Service converted.
	For.	Against.	For.	Against.	For.	Against.		
Service . .	Cheap; strong.	Aim bad .	Simple; cheap.	Too light	..	Bad . .	Small .	..
Enfield . .	Ditto .	Aim better	Ditto .	Ditto .	Very little	..	Ditto .	..
	Strong; good aim.	..	Simple; heavy.	..	Ditto .	..	Ditto .	..
Lancaster .	Good aim; moderate cost.	Weaker form.	Simple; wrought iron.	Costly; wrought iron.	Little, if with good wad.	..	Great .	Yes.
Armstrong.	Good aim; strong.	Costly; breech loader.	Heavy .	Costly; lead and iron.	Little .	Cannot load at muzzle.	Ditto .	..
Whitworth	Good aim	Costly; weak form.	Ditto .	Very costly fitted up.	Little .	Cost of fitting.	Ditto .	..
Britten . .	Ditto; cheap.	..	Ditto .	Compound lead and and iron.	Little .	Cost of lead.	Moderate	Yes.
Haddan. .	Ditto, ditto	..	Heavy; cheap.	..	Very little good wad.	..	Ditto .	Ditto.
Ditto, improved bore.	Ditto, ditto, strong form.	..	Ditto, ditto	..	Ditto, ditto	..	Small .	Ditto.

The ordinary service gun was of a strong and cheap form; but the aim was inaccurate. The projectile was cheap and simple in construction, but was too light, and there was too much windage. The strain upon the gun, due to the projectile, was small, but a heavy charge of powder was required, to make up for the loss by windage. There was no tendency to twist, or to burst open the gun, from the projectile acting as a cam. The Swedish gun was strong and cheap, the aim was better, the projectile was also cheap and simple, but was too light. There was little windage, and it was a great improvement upon the common gun. The Enfield gun, (small arm,) was strong, the aim was good, the projectile was long, and the form was simple. There was scarcely any windage, and but little strain due to the projectile. The Lancaster gun possessed good aim, and was constructed at a moderate cost. The form of the gun was simple, but it was weakened by the oval bore. The projectile was simple, being composed of only one material,—wrought iron,—but it was costly. There was but little windage, if a good wad was used. The projectile, had, however, a tendency to burst the gun. One advantage of the plan was, that the ordinary service gun could be converted into the Lancaster rifled gun. In the Armstrong gun the

aim was good, the projectile was heavy, but costly, on account of the fitting, and of its being composed of lead, antimony, and iron. The windage was small, from the projecting rings of lead and antimony on the projectile being larger than the bore of the gun; the projectile being introduced at the breech. The gun was very costly. In the Whitworth gun, the aim was good, the projectile was heavy, but it was costly in fitting up. In some cases the projectiles fitted the bore so closely, that upon putting a finger upon the touch hole, and pushing the projectile down the gun, it would spring back again on being released. The gun was very costly, and of rather a weak form. The material of which it was made was very expensive, but was admirably adapted for the purpose, being, in fact, a kind of mild steel. Mr. Britten's gun was of simple form, the aim was good, the projectile was heavy, and so far good; but being compounded of lead and iron, if a number were packed together, they would be liable to injure each other. The windage was small, from the lead expanding with the blast of the powder and filling the bore. The cost of soldering-on, or belting the projectile with lead, was not very great. Mr. Haddan's gun was cheap, the projectiles were a little cheaper than common shells, and were heavy,—weighing 92 lbs. for a 68-pounder gun. The windage was small, owing to the expanding wad, which filled the bore of the gun, and at the same time, kept the axis of the projectile in the centre of the bore, and quite steady during its passage out. The ordinary service guns were capable of being converted to this plan, for about twenty-five shillings each, and it could be done on the deck of a ship, as in the case of the Britten gun. The charge of powder was reduced from 16 lbs., the ordinary service charge, to 10 lbs., and the range was increased to 3,000 yards with excellent aim. In the improved form of bore, the tendency of the projectile to burst the gun was very small, and the form itself was strong, being nearly a circle.

With regard to the wire-bound gun, it remained to be shown, how the breech could be made of the same strength as the barrel, which could, undoubtedly, be made in that way. The strain upon the breech, at the time of explosion, was as much as upon the projectile and the sides of the gun. As to iron guns, cast, or forged in a solid mass, of mild steel, or of steely iron, he would propose to forge them hollow, so as to admit of their being cooled from the inside. He would use a stream of water, air, steam, or water and air, or water and steam, in the form of rain, and at the same time, thoroughly compress the outside upon the inside, as it cooled, by a heavy steam hammer; so that when the gun was quite cooled, the inside would be in considerable compression, and the outside in decided tension. The different circles, or rings of metal, between the outside and the inside, would then be in a

regularly graduated series. He believed that in this manner, the idea of various strains throughout the homogeneous mass, might be perfectly carried out; and he might say, more scientifically, than by any system of hoops, or wire.

He thought the question of attaining long ranges depended far more upon the strength of the metal of which the gun was composed, than upon the section of the rifle cuts, the speed of the twist, or the plan of breech loading. It was, no doubt, imperative, that the projectile should pass along the gun steadily, with some twist, and should have very little windage, in order that it might receive the full effect of the quantity of powder used. It was very much a question of the charge of powder and of the strength of the gun; as it was evident, that a charge of one-fifth the weight of the projectile, would send it further than a charge of one-ninth, or one-eighth.

Mr. W. STRODE said, he noticed that in the Table, (page 374,) the Enfield rifle was stated to be strong and of good aim. Now he believed, that on the contrary, the metal of the barrel was so weak, as to render it liable to injury from external causes, such as the fixing, or the taking off the bayonet. The projectile being too small, the aim was not good, and he thought the bullets often did not take the rifling at all. He had in his possession one o the regular service bullets, obtained from Aldershott, which was quite loose in the Enfield barrels.

Captain JERVIS, R.A., said, he was at a loss to understand the remarks just made. There was no such thing as an Enfield ball. The diameter of the service bullet had been slightly reduced, on account of the fouling caused by the powder, but the accuracy of the shooting had not been affected by that reduction.

Mr. LANCASTER thought the discussion upon this subject, elaborate as it had been, ought not to conclude, without some notice of what had been done by experimenters in other countries. Professor Daniel Treadwell, of the United States, had, for many years, directed close attention to this question. The results were given in a Paper, read before the American Academy,[1] remarkable for the acumen, learning, and deep research it displayed. The principle therein advocated, was that of using a cast-iron matrix, forming a screw on its outer circumference from end to end, and then applying wrought-iron rings, put on hot. On the outer circle of these rings, another screw was turned, when a second series of rings was added. Professor Treadwell obtained

[1] *Vide* "On the Practicability of constructing Cannon of Great Calibre, capable of enduring long-continued use under Full Charges." By Daniel Treadwell. From the Memoirs of the American Academy. (Mr. Lancaster presented a copy of this pamphlet to the Institution.)

the following remarkable results. He said, "My observations upon the lodgement have been made upon wrought-iron cannon. Between the years 1841 and 1845, I made upwards of twenty cannons of this material. They were all made up of rings, or short hollow cylinders, welded together endwise. Each ring was made of bars wound upon an arbor spirally, like winding a ribbon upon a block, and, being welded and shaped in dies, were joined endwise, when in the furnace and at a welding heat, and afterwards pressed together in a mould, by a hydrostatic press of 1,000 tons force. Finding in the early stage of the manufacture, that the softness of the wrought iron was a serious defect, I formed those made afterwards, with a lining of steel, the wrought-iron bars being wound upon a previously formed steel ring. Eight of these guns were 6-pounders of the common United States bronze pattern, and eleven were 32-pounders of about 80 inches length of bore, and 1,800 pounds weight. Six of the 6-pounders, and four of the 32-pounders, were made for the United States. They have all been subjected to the most severe tests. One of the 6-pounders has borne 1,560 discharges, beginning with service charges and ending with ten charges of 6 lbs. of powder and seven shot, without essential injury. It required to destroy one of the 32-pounders, a succession of charges ending with 14 lbs. of powder and five shot, although the weight of the gun was but sixty times the weight of the proper shot. If any of these guns are ever destroyed by firing them, the destruction will commence in the lodgement.

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"I cannot leave this subject, without observing, that I regard the late and still continued attempts to make wrought-iron cannon in Europe, by the process of fagoting, or piling, as a strange engineering delusion."

With respect to the Lancaster guns, it was true that three were burst at the muzzle in the Crimea; but it must be understood, that those which failed were the service guns, bored oval on his system, and not the guns specially made for the purpose. It was generally supposed, that the action of the shell, in passing out of the bore, burst the gun. The fact was simply, that the shells were originally made in two pieces; the base of the shell being welded to the upper portion. In practice, this weld was often imperfect. Hence, at the moment of the explosion of the service charge, the flame penetrated through the defective weld, to the charge within the shell. The charge, amounting to 12 lbs. of powder, was fully ignited, just at the moment the shell was in the act of leaving the muzzle of the gun. It could, therefore, only be a question of time, whether the shell burst within, or outside the gun. If the shell burst within the

muzzle of the gun, the destruction of the gun followed as a matter of course. Directly this failure in the manufacture of the shells was discovered, steps were taken to rectify it. Instead of being made of two pieces, the shells were now constructed of one piece of iron, and the muzzle of the gun had been strengthened, by the addition of a ring of wrought iron. Should, therefore, any of the old store of shells be used, by any chance, the gun would be strong enough to resist the contingency. It was found that these guns were now thoroughly equal to the requirements of the service.

Mr. C. W. SIEMENS said, many years ago he had some slight practical experience in the use of guns, and had watched, with great interest, the progress which had since been made in their construction. Addressing himself to the subject of the Paper, it had been objected, that a gun constructed upon the plan proposed by the Author, would not have sufficient longitudinal strength. It had occurred to him, that the longitudinal strength of the gun might be much increased, if instead of winding wire upon it, it was bound with corrugated bands of steel, put on spirally. He estimated, that two-thirds of the whole tensile strength of these bands would thus be made available for longitudinal strength. He proposed, that the core of the gun should be turned with spiral grooves, extending backward beyond the bore, and fitting the longitudinal ribs, or corrugation of the strips. The strips should be put on under varying tension, while the gun rotated in a bath of solder, in order to unite the several layers. He thought the core of the gun ought to be of equally hard and tough material, and he had no doubt, that the most serviceable gun would be one made of solid, but mild, cast steel, well solidified by hammering. Such guns were manufactured by Mr. Krüpp, of Essen. From a report made to the Prussian government by Colonel Orges, it appeared, that the German cast-steel gun had given the most satisfactory results, as regarded strength. A bar, 1 inch square, of this material, had borne a weight of 50 tons, whereas a bar of wrought iron of the same dimensions broke with 33 tons. Mr. Krüpp's gun bore five and a half times the internal pressure of an ordinary cast-iron gun of the same internal and external diameters, and three times the internal pressure which burst a bronze cylinder of the same dimensions. Mr. Krüpp was now making three hundred guns for the Prussian government. The weight of his 12-pounder breech-loading gun was 825 lbs. The cost of the forging was about £93, and that of the gun complete was £150. These figures would enable a comparison to be made with the cost of guns of other constructions. With regard to composite guns, he would suggest, that although they might possess greater strength against internal pressure, than a gun of homogeneous metal, yet such a gun would be more liable to injury, when hit by a hostile shot. A

composite gun would, he thought, suffer more from that cause, than a gun of homogeneous metal, which would only be indented by a shot; whereas the composite gun would probably be disabled.

Hitherto, comparatively few experiments had been made, to determine what the pressure upon the interior of a gun really was in firing, and also what was the resistance of the atmosphere to shot, at different velocities. In 1846, his Brother, Mr. Werner Siemens, suggested a plan to a commission appointed by the Prussian Government, the results of which had been published. He determined the velocity of the shot by making it pass insulated wires, in connection with a Leyden jar. The electrical discharge passing through the shot, caused a spark to go from a point, upon the polished surface of a steel cylinder revolving at high velocity, which it marked by a speck of burnt metal. The shot in striking other wires, at a given distance, would make another speck upon the polished steel cylinder, and the angular distance between those two points, would represent the time that was occupied by the ball in passing from the one place to the other. The results that had been obtained by this apparatus were, however, not quite satisfactory; and it had occurred to Mr. C. W. Siemens, that in order accurately to ascertain the forces acting in a gun, and also the resistance of the atmosphere to the passage of the projectile, an apparatus of a more simple nature might be constructed, which should record those facts, in the same way that the exact pressure of steam in a steam cylinder, at every portion of the stroke, was arrived at. His object was, in fact, to indicate the forces acting upon the projectile throughout its flight. For this purpose he proposed to employ a hollow shot with open ends, closed by strong doubly-dished steel plates, laid one upon another, with lead plates between. When the shot was fired, the gases of the powder would act upon the end diaphragm, the pressure upon which would, in fact, urge the shot along. It was important to reduce the inertia of the elastic medium to the lowest possible amount, in order that it might instantly obey a change of pressure. The motion of the centre of the diaphragm was imparted to a scribing point in contact with a disc, made to rotate, during the flight, with a given velocity. It appeared difficult, at first sight, to obtain a uniform velocity of this disc without clockwork, which was, evidently, inadmissible; but an arrangement had occurred to him, by which he expected to effect that purpose. He fixed upon the disc two small fuses, or rockets, acting in opposite directions. If both these rockets were made of equal power, it was evident, that no rotating motion would ensue; but the one being made equal to only about two-thirds of the other, the more powerful jet would accelerate the wheel, until it was balanced by the lesser jet, on account of the negative motion imparted to it. A moderate and remark-

ably uniform rotation might thus be produced, for the power of the larger jet would diminish, as the square of the diminished relative velocity between the escaping gases and the wheel; whereas the power of this counter jet would increase, as the square of the increased relative velocity between the gases and the wheel. A small retardation of the wheel, by friction, or otherwise, would, consequently, produce a great change in the relative power of the two jets. These fuses were lighted, the instant the shot was dropped into the gun. Cards of zinc plate were fixed to the sides of the rotating disc, covered first with a black and then with a white varnish, whereupon the scribing point would trace a very clear line. Whilst this wheel revolved, a circular line would be obtained, until the pressure upon the steel disc caused the scribing point to ascend, producing a spiral indication of the pressure at all intervals of time. The disc in the front of the projectile was much lighter, being intended to indicate the resisting pressure of the atmosphere, by a line upon the other side of the rotating wheel. The negative pressure of the atmosphere against the back of the projectile might, also, be recorded by a similar arrangement. The diaphragm behind, should, in that case, be made very slight, and be covered by a strong metallic plate, to resist the force of the gunpowder, which plate would separate from the projectile at the mouth of the gun. In the same way, the pressure upon any portion of the curvilinear front surface of the projectile might be indicated, by making, instead of one opening in the centre, several openings in a circle around it. In order to maintain atmospheric pressure inside the projectile, its sides were perforated by a number of small holes. The weight of the moving mechanism need not exceed 6 ounces, and considering its strength and simplicity of arrangement, he did not apprehend any force, less than that which would destroy the shell itself, would interfere with its proper action. The advantages that would be obtained by such a complete record of the forces acting upon projectiles, under different circumstances of charge, form and speed, would, he thought, be very great, not only with regard to the construction of ordnance, and to balistic laws, but to science generally, in affording useful information regarding the nature of fluid resistance. The experiment could be tried with any gun, and at a small expense; and if the proper authorities should think his proposal worth the trial, he should most readily give his services in the matter.

Mr. CONYBEARE said, it appeared to him, that the first step in the present inquiry should be, to determine the maximum amount and the *modus operandi* of those forces tending to disruption, to which guns were subjected in service, and which it was required they should endure, without injury to their fabric. These forces were; first, the disruptive force of the powder, which was depen-

dent on its quality, on the amount of the charge, on the diameter of the cylinder in which it acted, and on the amount of windage; and secondly, the inertia and friction of the projectile, the inertia being a function of the weight and elongation of the bullet, and the friction being dependent on the angle of the twist, and on whether the projectile was made with projections to fit the grooves, or had to be forced into them by the explosion.

The total mechanical effect of powder, exploded in rigidly closed chambers, might be readily determined, by experiments on the minimum bursting charge of shells, varying in diameter, or in thickness of metal. For example, the 12-lbs. shrapnel shells used in the United States service, were 4·6 inches in external, and 3·6 inches in internal diameter. When one of these was split into two pieces, by internal pressure, the area of fracture was rather less than 6½ square inches; and taking the tensile strength of the iron at 25,000 lbs. per square inch, it would show, that a force of about 72 tons must be exerted, at the moment of disruption. If the action of the powder was diffused, by its being commingled with the balls, the requisite bursting charge was 4 oz. In Captain Dahlgren's new arrangement, where the balls were imbedded in two hemispherical masses of sulphur, leaving a cylindrical cavity for the bursting charge, in the axis of the shell, even three-quarters of an ounce of powder sufficed to generate the requisite disruptive force of 72 tons. But no large gun could be manufactured, to endure a disruptive force so enormous, in proportion to its charge, as 72 tons for each three-quarters of an ounce of powder exploded. Nor could any gun be subjected to such a stress in service; for so large a ratio of pressure, to weight of powder, could only be obtained, in the case of explosion in a chamber absolutely and rigidly closed. The smallest vent would act as a safety valve, and would reduce the explosive force to a mere fraction of its amount, in a rigidly closed chamber. This was demonstrated by the experiment, originally tried at Woolwich, and described in Mr. Greener's treatise on "The Gun."[1] He said:—"screw into each end of the breech part of a gun-barrel a well-fitted plug, then having filled the barrel with powder, drill a communication and screw in a nipple, in one of the plugs, fire a cap on it, and the explosive fluid will stream out from the small orifice like steam from a pipe, till it is expended." Mr. Greener repeatedly tried the experiment, and had thus fired 2 oz. of the best powder, without any violent motion being communicated to the barrel. Now, if a charge of three-quarters of an ounce sufficed to exert a disruptive force of 72 tons, in the case of the shell, 2 oz. under similar

[1] *Vide* "The Gun; or, a Treatise on the various descriptions of Small Arms." By W. Greener. 8vo. Sunderland, 1835. Page 36.

circumstances, would exert a disruptive force of 4,313,000 lbs., or upwards of 141,000 lbs. per square inch on the area of pressure in Mr. Greener's experiment, taking the area of pressure in the interior of the breech at 3 square inches. It was known, from the United States experiments, that the breech end of the strongest musket barrel was permanently bulged, by a hydrostatic pressure of about 13,000 lbs. to the inch. Therefore, assuming the pressure in Mr. Greener's experiment to have been within three-thirteenths of the ultimate strength of the barrel, it would only be one-tenth of the pressure that would have been exerted, had not the vent used for firing the powder been left open. In gunnery practice, in addition to this vent being always open, one end of the explosion chamber was only closed by a movable projectile. It appeared to him, that the indications of the balistic pendulum were fully adequate to the determination of the stress that guns were subjected to, in actual service. But if any more direct evidence was required, it would be afforded by the United States experiments, on the extreme proof of cannon and musket barrels under hydrostatic pressure. These were tried, to determine the relative power of iron to resist a direct tensile force, hydrostatic pressure, and the fire of gunpowder. They led to the conclusion, that for cast-iron ordnance, the hydrostatic proof could not be safely extended, without permanent injury to the gun, beyond from 3,000 lbs. to 4,000 lbs. to the square inch. This pressure, the experimenters would thus seem to have considered, as equivalent to the stress to which the guns were subjected, under the ordinary proof discharges of powder and ball.

Some high authorities were, at present, disposed to decry cast iron, as a material unfitted for the construction of ordnance of any description. But he thought such a conclusion was based on wholly insufficient grounds. Considering the enormous number of proof discharges that really good cast-iron guns would withstand, and the great improvement that had been effected in America in their material, in their form, and in the method of casting them, he was convinced, that the gun of the future, for naval purposes and for land batteries, would be of cast iron. In short, that cast iron, in the present improved method of preparing it, combined the requisite hardness and tenacity, with cheapness, more perfectly than any other material. Many of the improvements, to which he alluded, were recorded in the volume of United States Reports, a copy of which he begged to present to the library of the Institution.[1] In addition to these experiments, ever since 1841, by the

[1] *Vide* "Reports of Experiments on the Strength and other Properties of Metals for Cannon. With a Description of the Machines for testing Metals, and of the Classification of Cannon in Service." By the Officers of the Ordnance Department, U. S. Army. 4to. Philadelphia. 1856.

regulations of the U. S. Ordnance Department, an officer had been required to be in constant attendance at the foundries, while the cannon were being made, to examine and test the metal before it was used, as also in the first gun made, before another was cast from the metal. This system of inspection had resulted in increasing the average tensile strength of iron cannon, cast in the United States, from 23,638 lbs. to 37,774 lbs. per square inch, and its maximum tensile strength to 45,970 lbs., with a density of 7,304. This high average result was conclusive, as regarded the adaptation of cast iron, when properly treated, to the manufacture of ordnance; for it must be remembered, that the tensile strength of bronze gun-metal could scarcely be taken at more than 30,000 lbs. The second result of these experiments had been to show, that iron guns cast hollow, according to the plan of Lieut. Rodman, of the United States Artillery, had from eleven to twenty times the duration of guns of the same pattern cast solid, at the same time and from the same metal. Another improvement, which was due to Captain Dahlgren, consisted in the exact adaptation of the thickness of metal, in each segment of the length of the gun, to the amount of the disruptive force to which such particular segment was subjected, on the discharge of the gun. The mode by which these forces were measured might be thus described:—At rather more than one calibre in the rear of the muzzle, a transverse bore was drilled, from the exterior surface of the experimental gun into the chase. Into this transverse bore, a projectile of ascertained weight was exactly fitted. The gun was then loaded and discharged. As soon as the ball had passed, and the exploding gases had reached the transverse bore, its projectile was propelled against a balistic pendulum, by which the force, with which it was discharged, was exactly measured. A series of similar transverse bores were then drilled, consecutively and at equal intervals, from the muzzle end to the chamber; each being, in succession, closed with a projectile of precisely the same weight as that of the first, and the force with which each successive projectile was discharged, being similarly measured and recorded. The relative force of these successive discharges was a measure of the relative force of the explosion, in each corresponding segment of the chase;[1] and consequently, of the relative thickness of metal required in each such segment. These experiments proved, that in guns of the common model, the weight of metal, between the trunnions and the muzzle, was greatly in excess. In the model deduced from these experi-

[1] In the United States Reports, an instrument is mentioned, invented by Lieutenant Rodman, and authorised by the Washington Board of Ordnance, for determining the successive increments of velocity communicated to the ball, in its passage through the bore. This instrument is stated to have satisfactorily answered the intended purpose.

ments, and which, under the designation of the Dahlgren gun, had superseded the old patterns in the United States service, the weight of metal, between the trunnions and the muzzle, was greatly reduced. The metal, thus saved, was placed about the breech, where strength was chiefly needed. The result of these improvements had been, to enable the United States to replace the 32-pounders, weighing 57 cwt., previously used in their vessels of war, by Dahlgren guns, which, though not materially differing from the old 32-pounders, either in weight, length, or range at equal elevations, had the great advantage of throwing an 8-inch ball, in place of a 32-lbs. ball. Dahlgren guns, 12 inches in diameter, had withstood every proof, and were now adopted as pivot guns in the United States Navy.

Of the experiments recorded in the United States Reports, those on the extreme proof of cast-iron ordnance, under hydrostatic pressure, and of casting guns hollow, on chilled cores, were so instructive, as to the molecular arrangement of the particles, in heavy masses of cast iron, and so suggestive, in respect to the modes of treatment that were to be avoided, and of those that were to be adopted, in the construction of a cast-iron cylinder intended to resist internal pressure, that he would briefly describe them.

In the experiments tried to ascertain the relative capability of cast-iron ordnance, to resist a direct tensile force, the fire of gunpowder, and hydrostatic pressure, four guns were subjected to the extreme hydrostatic proof. With the first, an 18-pounder, when the pressure reached 7,000 lbs. to the inch, the water came through the pores of the metal, in several places, forming small mounds of white froth, which afterwards collected in drops, and fell off in small streams. When the pressure was extended to 9,000 lbs., the gun burst with unexpected violence, one fragment weighing 170 lbs. being projected 21 feet. The second gun was a 24-pounder, of a very heavy model. Proof bars cut from the trunnion exhibited a good quality of iron. The water began to exude at 9,000 lbs.; and with a pressure of 9,500 lbs., the water was projected in several rills through the metal, to such an extent as to reduce the pressure to 5,000 lbs. and thus to terminate the experiment. The third gun experimented on, was another 18-pounder. This burst, when the pressure reached 9,860 lbs. on the square inch. The fourth gun was a 6-pounder. This had endured, without injury, thirty-six proof fires of the usual ascending series; fourteen being of the maximum charge of 3 lbs. of powder and sixteen balls, and then two extra charges of 6 lbs. of powder and seven balls. The thin portion, near the muzzle, separated from the thicker portion by a groove turned in the metal, for the purpose of the proof, was burst with a pressure of 12,400 lbs., and the thicker portion of the chase was burst by a pressure of

20,000 lbs. on the square inch. The metal appeared impermeable, and no water traversed the pores, at any stage of the operation. A circumstance attending these trials, strikingly illustrated the porous character of the interior of guns cast solid, the impermeability attained by the rapid cooling of the surface of a casting, and the consequent advantage of casting guns hollow, and of cooling them from the inside. The experimenters reported, that hydrostatic proof could only be applied to guns which had been turned after casting, "as the hardened crust of chilled iron on their exterior surfaces, arising from the coldness of the mould, would prevent the penetration of the water, and thus afford no indication of the existence of imperfections in the body of the metal." Cases occurred during the experiments, where the force of water collected under this crust, through a fissure in the mass of the metal beneath, had raised it in the form of a spherical segment of an inch in projection above the surface of the gun; and not until this blister was broken through, by an increased pressure, was there a leak of any kind to indicate the flaw.

Surely the canon, in Hydraulic Engineering, "that every structure intended to resist the impact of water, should be impermeable by water," applied with tenfold force, to a fabric intended to resist the intense force of the gases set free by the ignition of powder, calculated as they were, by their extreme tension, to search out every fissure and to permeate every pore, in the material of the gun chase. Such repeated permeation of the pores of the metal, by incandescent gases acting injuriously on the iron, chemically as well as mechanically, and by their heat, must, necessarily, destroy the gun in a much less number of rounds, than it would endure, if its interior surface was impermeable. As the practicability and advantage of giving impermeability to the interior surface, by casting it hollow, on a chilled core, and of cooling the metal from the interior, instead of from the exterior, had been fully established, it appeared to be a very unscientific proceeding to continue to cast iron guns solid. The mode, hitherto adopted, of casting iron ordnance solid, and cooling them from the exterior was, moreover, by subjecting the interior of the metal to extension, and the exterior to compression, exactly the converse of the conditions of maximum efficiency. It was admitted, that the material, of which a gun was composed, should be so disposed, as to present a sound and impermeable surface to the ignited powder, and to have the metal, adjoining the interior surface of the tube, in a state of compression, and that adjoining the exterior, in a state of extension. These conditions were precisely the converse of those actually obtaining, in the case of a gun cast solid, and cooled from the exterior; but they were fully complied with, when the gun was cast hollow, and was cooled from the interior. No one would think of commencing the construction of a gun built up of a number of concentric layers

of wrought-iron rings, by heating the second ring, and placing it within the exterior ring already cooled and shrunk; and when the second ring had cooled, repeating the operation with a third red-hot ring. It was manifest, that a gun so formed, would have air spaces between each layer of rings, and would be wholly destitute of coherence and strength. The failure of such a gun could not, however, be fairly attributed to defects in its material. Yet this was precisely the mode of proceeding adopted, in the construction of cast-iron ordnance, cast solid and cooled from the exterior. A gun so cast and cooled might be considered as composed, or built up, of a series of thin concentric layers, or rings, formed by successive congelations, one within another; the exterior ring being congealed by contact with the cold surface of the mould; the second ring forming at the cooling point of the metal, upon and within its exterior predecessor, and so on. The exterior of the casting would thus have cooled down to a temperature at which contraction had ceased, while the interior remained at the melting point. The result would be, as stated by Mr. Mallet, that "in a casting of 2, or 3 feet, or more in diameter, it is not unusual, (with the founder's best care,) to find a central portion of from 6 to 8 or more inches in diameter, consisting of a spongy mass of scarcely coherent crystals of cast iron, usually in arborescent masses, made up of octohedral crystals; the whole so loose, that upon a newly-cut section, dark cavities can be seen by the naked eye in all directions, out of which often, single, or grouped crystals can be picked with the hand, and so soft, that a sharp-pointed chisel of steel may be easily driven into the mass some inches, as if into lead, or soft stone."[1] It was true, that a large portion of the defective core of spongy metal was usually removed, by the process of boring out; but still, soft spots were left, which were easily bruised and burnt away, by the shock and blaze of the powder. And even if free from such flagrant defects, a gun, so cast and cooled, must, inevitably, have the texture of its metal loosest, where it ought to be closest; and that portion of its material in extension, which ought to be in compression, and *vice versâ*. On the other hand, when a gun was cast hollow and was cooled from the interior, the concentric layers, or rings, formed by successive congelations, were each, so to speak, shrunk on, outside its congealed and contracted predecessor, just as in a built wrought-iron gun; the interior was thus put into a state of compression, and the exterior into that of extension, which were the conditions of maximum efficiency.

The United States experiments had demonstrated, both the practicability of casting guns hollow, on a chilled core, and also the immense superiority in durability, possessed by guns so cast, over

[1] *Vide* "On the Physical Conditions involved in the Construction of Artillery, &c." By R. Mallet. 4to. London. 1856. Pages 20 and 21.

those cast solid and cooled from the exterior. In these experiments, three pairs of guns were cast; two pairs of 8 inches, and one pair of 10 inches calibre. Each pair was cast from the same iron, melted in two furnaces, which discharged, by separate streams, into a common reservoir, whence it issued in a single stream, and dividing, filled both moulds simultaneously. One of each pair was cast solid, in the usual manner, and the other, according to the plan invented by Lieutenant Rodman, was cast hollow, by means of a core, formed on a tube of cast iron, through which a stream of water constantly circulated, while the iron was cooling. The core tube was water tight, and was closed at the lower end. The water was admitted through an interior tube, descending nearly to the bottom of the core tube, and the water then ascended through the annular space between the two tubes, and was discharged from the core, at a point above the casting, flowing off in a heated state. In the first 8-inch guns so cast, the flow of water through the core, was continued for forty hours. The core was then withdrawn, and the water was passed through the interior cavity formed by the core, for twenty hours more. The total quantity of water passed through, was 6,000 cubic feet. In the case of the second 8-inch gun, 10,000 cubic feet of water were passed through, in sixty-five hours; the core having been withdrawn after the first twenty-five hours. In the third case,—a 10-inch gun,—22,560 cubic feet were passed through in ninety-four hours, when an unsuccessful attempt was made to withdraw the core. In each case a fire was kindled at the bottom of the pit directly after casting, and was continued during sixty hours. The pit was covered, and the iron case, containing the gun mould, was kept at as high a temperature as it would safely bear, being nearly at a red heat all the time. Each pair of guns, thus cast simultaneously, and from the same metal, the one hollow, and the other solid, were simultaneously proved. The results, which were given in detail, proved, that the endurance of the gun which was cast hollow, greatly surpassed that which was cast solid. The difference, in one case, was more than twenty to one, in which case the gun which was cast hollow remained uninjured, after fifteen hundred discharges, and one thousand additional discharges had been, subsequently, recorded, whilst that which was cast solid, burst at the seventy-third round. In the aggregate of all the cases, the difference was as eleven to one, in favour of guns which were cast hollow. From the precautions taken to insure identity of material in both guns, of each pair, and for preserving an exact uniformity in the proof of each, the great difference of endurance must be ascribed solely to the different methods of cooling the castings.

Now considering the proofs recorded to have been borne with impunity, by certain old-fashioned iron guns, notwithstanding the disadvantage they laboured under, in having been cast solid, which

guns had been fired repeatedly, with a charge of powder equal to the weight of the ball and with seven balls, or with a charge half the weight of the ball and sixteen balls, it might reasonably be expected, that when cast hollow, and with the additional advantage of the diminished calibre and charge of the modern rifled cannon, the same material, if judiciously treated, would be found adequate to any strain to which it could possibly be subjected in service.

The method of casting hollow, on a chilled core, might be obviously applied, with increased facility, to a breech-loading cannon; for the continuity of the bore would allow of the more exact centering of the core. Indeed the core might be so accurately fitted to the calibre, as to permit the gun to be bored out and rifled, without penetrating the crust of chilled metal formed on the core. Such a gun, by presenting an absolutely impermeable surface to the exploding gases, would prove almost indestructible. It would further conduce to strength and durability, and to preserve the hardened crust formed on the exterior surface by the contact with the mould. This was done with the iron guns cast at the Belgian Government foundry, at Liège, where instead of turning off the crust, as was the practice with guns manufactured in this country, the guns were only bored and finished, without removing any part of the outer skin. He believed the cast-iron gun of the future would be cast hollow, on a chilled core, and that the exterior crust would be preserved. The exterior should be plain, and devoid of the ornamental astragals, reinforces and sudden changes of thickness, which, owing to the rĕ-entering angles they produced, and the planes of weakness they created, by their effect on the interior crystallisation of the iron, so frequently originated and were coincident with, the lines of fracture. The thickness of metal in the chamber, and thence to the muzzle, should likewise be proportioned by the Dahlgren formula. He thought it should be a breech-loader; and he believed the Whitworth arrangement would, probably, be found better adapted to cast-iron guns, than the Armstrong system, in which the cylinder of the gun was weakened by the slot required for the moveable breech. The rifling should be free from re-entering angles, which were a source of weakness in cast iron, and it should be such as to weaken the cylinder, in the least possible degree. The form that would best answer these conditions, and which was shown in Fig. 27, would be one that would bear the same relation to the three-grooved rifle, that the Lancaster oval did to the two-grooved rifle. Hexagonal rifling would be inapplicable to cast-iron guns, on account of the re-entering angles it would present to the exploding gases. Projectiles exactly fitted to the form of the rifling, now suggested, might be cheaply manufactured by self-acting shaping machinery.

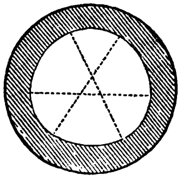


Fig. 27.

The present tendency of naval armament appeared to be, to place heavy guns, intended to fire at extreme ranges, and consequently, with high trajectories, on board comparatively small and unsteady craft. Under such conditions, the most practised marksman would seldom succeed in hitting a distant object, unless he had the means of instantaneously discharging the piece, at the exact moment, in the roll of the vessel, when the object was covered. To secure this result, it was desirable that some arrangement should be devised, by which the marksman, looking through a telescope exactly parallel with the line of aim, might discharge the piece at the lucky instant, as if he fired from the shoulder, and with a hair trigger. For coast defences, it would be advisable to establish a telegraph communication with two posts of observation, two, or three miles distant to the right and left of the battery. From these observing stations the exact bearing, or angle subtended by the direction of the battery, and that of an enemy's vessel in sight, might be instantaneously and cotemporaneously telegraphed to the battery, where, by means of the intersection of two rules, on a graduated plane table, the exact distance of the vessel from the battery might be ascertained at any moment, without any process of calculation.

In recording experiments on various descriptions of rifled arms, it appeared desirable to adopt a common standard of ratios, in registering the elements of each, as by this means, alone, could a fair comparison be instituted between them. These elements were four in number, of which the first three were the more important. First, the ratio of the weight of the charge to the weight of the projectile; which ratio, supposing the bore of sufficient length to burn the powder, determined the 'initial velocity.' Secondly, the ratio of the weight of the projectile in pounds, to each square inch in the area of its cross section; on which ratio depended the loss of velocity of the projectile during its flight. Thirdly, the ratio of the twist to the calibre, as one turn in so many calibres; on which depended the accuracy of flight and the amount of elongation that might be given to the projectile. And fourthly, the length of the chase, or bore in calibres; as unless this was sufficiently long, the powder would not produce its full effect. This last element would be affected by the description of powder used, whether fine, or coarse-grained, and on the ratio of the space occupied by the powder to the capacity of the chase. The ratio of the charge of powder to the weight of the projectile, ranged from one-tenth to one-fourth; and the ratio of length of bore to the calibre, from 25 to 1, to 88 to 1. As regarded the rate of twist, measured in terms of the calibre, according to Major Croquillet, of the Belgian artillery, the turn of the grooves should be to each other, in all rifled arms, as their calibres, provided the projectiles were similar. Colonel Theroux of the French artillery,

gave a similar formula, for determining the proper twist of grooves, for firing elongated balls. H (the helix, or twist) = 56·8 D; D being the diameter, or calibre. This rate of twist was also found to be the best, in General Jacob's experiments, and was adopted in his pattern rifle. The ratio of twist to calibre, ranged from 1 turn in 20 calibres, to 1 turn in 136 calibres. In the case of each particular gun, or rifle, all four ratios,—weight of powder to that of projectile,—weight of projectile to cross section,—rate of twist,—and length of bore,—must be considered together, and in connection with each other. For there were different means for effecting the same ends; and in many cases, a deficiency in one of the four ratios might be made up by an excess in another. Thus, in the case of the twist, its object was to give a certain amount of rotation to the ball, as it left the muzzle. This requisite amount of rotation might be obtained, either by means of a rapid twist combined with a low initial velocity, or by a slower twist, combined with a high initial velocity. The first mode was adopted in the rifle of the Sardinian Bersaglieri, where, with a projectile 0·65 in diameter, not a diameter and a half in length, and weighing 530 grains, the charge was only 54 grains, or little more than one-tenth. The initial velocity was, consequently, exceptionally low, and a very rapid twist was required, to establish the necessary rotation in the balls. The twist was, accordingly, 1 turn in 17 inches, or in 26 calibres. The second method was adopted in the Swiss Federation rifle. In this, instead of one-tenth, the charge of powder was one-fourth of the weight of the ball. This produced so high an initial velocity, that 1 turn in 77 calibres sufficed to establish the requisite amount of rotation in the ball. Each of these two methods would secure equal accuracy, in firing at a mark, at a known distance; but the Sardinian rifle ball would have a much higher trajectory, and much less penetration, than the Swiss. Rapid rotation could not be combined, beyond a certain extent, with a high initial velocity, unless the projectile was made with projections to fit the grooves. Without such projections, at high initial velocities, the ball would 'strip,' or be driven out without taking the rifling. Hence those experimenters who, like General Jacob and Mr. Whitworth, had obtained the greatest results, by discerning clearly the advantage of combining the accuracy of rapid rotation, with high initial velocity, and its consequence, a flat trajectory and great penetration, had adopted projectiles made with projections to fit the grooves; and he believed, such projectiles were destined to supersede those which were forced into the guns by the explosion of the powder. There was one disadvantage attendant on an increase of twist. It increased the 'drift,' or tendency of the ball to carry to the right of the line of aim, when the turn of the rifling was from left to right, and to carry to the left when the rifling was in

the contrary direction. Thus, though 1 turn in 57 calibres was considered the most advantageous in other respects, the French Commission adopted a twist of 1 turn in 135 calibres, to reduce this drift. The drift might be diminished by grooving the projectile transversely. It was found that the drift of cylindro-conic balls, like the Enfield, without grooves, fired from rifles, but with the same twist as the Enfield, was 10 feet in 872 yards; with grooves, the drift was inappreciable, at the same distance. It was probable, that the projecting angles of the Whitworth hexagonal projectile answered the purpose, as well as grooves.

It was also found, in the experiments tried by the French Commission, that when the centre of gravity of an elongated projectile was near the front, the point of such projectile drooped below the trajectory, in its flight; that when the centre of gravity was near the rear, the tail drooped; but that when the centre of gravity was in the centre of the length of the projectile, the axis of such projectile remained coincident with the line of trajectory, throughout its flight. It was obvious, that the resistance of the air would be at a minimum, in the last case, and this explained the improvement that was effected in the range of the Whitworth projectiles, by tapering them in the rear as well as in the front. By increasing the twist, it became practicable to increase the elongation of the projectile to the extent of seven diameters, if such a projectile was annularly grooved. But the elongation of the projectile was limited by other considerations; and it was now established, that from two and a half to three diameters would be the utmost amount of elongation adopted, save in exceptional cases.

The loss of velocity in the projectile, from atmospheric resistance, during each second of its flight, depended on the ratio of its weight, to the area of its cross section. This ratio might be conveniently expressed in terms of the weight of the projectile, in pounds for each square inch of the area of its cross section. For example, in the Armstrong 3-inch gun, the area of the cross section of the bore, or projectile, would be about 7 square inches; and the weight of the projectile being 12 lbs., the ratio of weight to atmospheric resistance would be $\frac{12}{7}\frac{\text{lbs.}}{\text{square inches.}} = 1\cdot71$ lb. per square inch. In the case of a rifle ball $\frac{1}{2}$ inch in diameter and weighing 1 oz., the area of its cross section would be about $0\cdot2$ square inch, and its weight, $0\cdot0625$ lb. The ratio of weight to resistance would, consequently, be $0\cdot313$ lb. per square inch. The appended Table, (page 392,) gave the elements of twelve of the most approved rifled arms.

He had already observed, that equal rotation, and consequently, equal accuracy might be obtained, either by combining a small charge in proportion to the weight of the ball, that was to say, a low initial velocity with a very rapid twist, or by combining a

Name of Gun.	Dimensions and Quantities.								Ratios.				
	1 Mode of Rifling. Number of Grooves.	2 Twist, one Turn, in Inches.	3 Length of Bore, in Inches.	4 Calibre, in Inches.	5 Area of Calibre, in Square Inches.	6 Length of Projectile, in Inches.	7 Weight of Projectile, lbs.	8 Charge of Powder, lbs.	9 Weight of Powder in terms of Weight of Projectile. Projectile = unity.	10 Weight of Ball to resistance, in lbs. per Square Inch.	11 Twist to Calibre, one Turn, in Calibre.	12 Length of Bore, in Calibres.	13 Length of Projectile, in Calibres.
Rifled Cannon.													
Whitworth's 80-pounder Gun	Hexagon	120	118	5·	16·125	..	80	10	0·125	5·	24	25	..
Whitworth's 12-pounder Gun	Ditto	60	93	3·25	6·72	..	12	2	0·166	1·76	20	30	..
Armstrong's 12-pounder Gun	32	114	75	3·	7·07	..	12	1½	0·166	1·69	38	25	2·25
Whitworth's 3-pounder Gun	Hexagon	40	72	1·5	1·462	..	2·5	5	0·200	1·71	26·6	48	..
Rifled Small Arms.							Grains.	Grains.					
Sardinian Rifle (Bersagliere)	8	17	..	0·65	0·332	·9	530	54	0·102	0·228	26·1	..	1·303
Whitworth's Rifle	Hexagon	20	39	Major axis, 0·49	0·139	1·45	520	68	0·132	0·534	46·	88·	3·00
Jacob's Rifle	4	30	24	0·529	0·22	1·31	754	94	0·125	0·490	56·7	46·	2·50
Lancaster Rifle	Elliptic	32	32	0·498	0·196	1·12	520	68	0·132	0·379	64·	64·	2·25
Swiss Federal Rifle	8	36	33	0·41	0·132	1·	257	62	0·243	0·278	76·8	80·6	2·44
Enfield Rifle	3	78	39	0·568	0·254	0·96	520	68	0·132	0·292	135·5	68·5	1·69
French Line Rifle	4	78	38	0·68	0·363	0·9	494	77	0·156	0·195	114·7	56·	1·32
Belgian Rifle		78	38	0·66	0·342	Pewter ball, 1·19	725	85	0·118	0·32	118·	57·5	1·80

higher initial velocity with a slower twist; but that though the accuracy was the same in both cases, the latter method gave a flatter trajectory and greater penetration. Similarly, there were two methods for obtaining equal ranges; first, by combining the use of low initial velocity with that of a projectile of high 'maintaining power,'—or, one whose weight bore a high proportion to its surface of resistance; or, secondly, by combining a higher initial velocity with a ball of lower 'maintaining power.' The latter principle, which was best carried out in the Swiss rifle, had the advantage of attaining the same results, with a smaller weight of projectile; thereby diminishing the recoil, and enabling the soldier to carry a larger number of rounds of ammunition.

The most important ratios in the Table were those given in columns 9 and 10, which determined the "initial velocity," and the "maintaining power" of the projectile. The comparative initial velocity, in the various cases, would be directly as the numbers set opposite to them, in column 9, and the maintaining power of the ball, directly as the number set opposite each, in column 10. The maintaining power was due to diminishing the loss of the ball's velocity, during its flight, by reducing the ratio of its resistance, or cross sectional area, to its weight. This might be done, either by increasing the weight of the ball, without altering its proportion of length to diameter, or by reducing its diameter and cross section, and increasing its length, without altering its weight. The latter method was the best, and was carried to its utmost extent in the Whitworth rifle. It must be remembered, that the ratios of maintaining power, given in column 10, assumed that the ball was so balanced in the centre, as to fly with the whole length of its axis coincident with the line of trajectory, throughout its flight; but if the centre of gravity was not in the centre of its length, the ball would droop either in the front, or the rear. The axis being then inclined to the line of trajectory, the resisting surface would be commensurately increased, and the maintaining power would be diminished.

The three great principles of effect, in rifled projectiles, were:—initial velocity, maintaining power, and rotation. Neither should be carried to such an extent as to interfere with the due application of either of the other two, and the perfection of a rifled arm consisted in the happy combination and due relative proportionment of all three conditions.

The conditions that should be fulfilled by the form of rifling, both in respect to the projectile and in respect to the gun, would appear to be, that the projectile should be of such a profile, as to admit of its being economically constructed and shaped by machinery, so as to fit the grooves of the bore with great accuracy. It should be simple and not liable to injury in carriage, and it should take the rifling without friction. The form of rifling should

be such, as should avoid re-entering angles, and should weaken the gun in the least possible degree. The projectiles used for rifled ordnance were divisible into two great classes:—Those made with projections to fit the grooves; and those without such projections, but which being of lead, or coated with lead, were forced into the grooves, by the explosion. In the infancy of rifled cannon, it was assumed, that the only efficient method of eliminating windage, was by the adoption of a lead-coated ball, forced into the grooves, by the explosion. But experience had since shown, that by the use of a simple cast-iron shot, shaped to the rifling by machinery, and provided with a greased wad, the windage might be reduced equally well, and without subjecting the gun to the great increase of strain and to the friction incidental to the use of the 'forced ball.' As such simple shot, made with projections to fit the rifling, could be fired with a quicker twist, without the possibility of stripping, were cheaper to manufacture, less injurious to the gun, and much less liable to injury, in carriage, there was little doubt, in his opinion, that ere long, they would supersede the forced balls.

Major-General ANSTRUTHER said, there was an apparent error in speaking of cast iron as being of uniform strength, and of gunpowder as having a fixed force. He had seen an English 8-inch cast-iron shell, which could not carry its own weight, filled with lead, and thrown with 2 ounces of powder, to a distance of 150 yards. He had known the strength of powder to vary so much, as with the same weight of charge, in one case to throw a given projectile to a distance of 300 yards, and in another to 1,200 yards. In the former instance the powder was of Chinese, and in the latter of English, manufacture.

Mr. PEARSON proposed to confine the few remarks which he should make to the construction of a gun to withstand the greatest amount of internal pressure; as, although he had some opinions with respect to a particular kind of shell, and to the principle upon which a gun ought to be rifled, he thought those questions deserving of separate and distinct discussion. Previous to the Great Exhibition of 1851, he had made a gun, on a principle of his own, but was persuaded not to bring it forward on that occasion. He thought the gun should be made of wrought iron, and that the grain, or fibre of the iron should be placed in such a direction, as to enable the whole of its strength to be employed in resisting internal pressure. In welding the gun, care should be taken to heat the iron properly, and to work and use the material to the greatest advantage, when so heated. He believed, that a wrought-iron gun could be made of one-half the weight of a cast-iron gun, to carry the same weight of shot, and to do the same amount of execution. He then proceeded to describe two ways of making guns. In the first, a bar of iron was coiled

spirally round a steel tube, which formed the bore. The outer case was to be welded together, so as to become one piece when finished. A square thread was then to be cut on the outside of the steel tube, and a corresponding one on the inside of the iron case. These should be so arranged, that when the iron case was heated to a blood-red heat, and the steel tube was screwed in, proper appliances being provided for the purpose, there should be a sufficient amount of contraction to cause the iron case to bind the steel tube firmly. The thread of the screw need not be more than $\frac{1}{16}$th of an inch deep. Supposing there happened to be a defect in the welding of any joint in the outer case, the thread on the steel tube would help to keep it firmly together. In fact, he did not think one could separate from the other, without the bursting of the gun itself. When the steel tube was worn out by service, by heating the iron case, and unscrewing the old tube, it could be replaced with a new one; and thus a perfect gun be obtained for the cost of a new tube. The iron gun, or case would answer for a series of steel tubes. The second plan was to coil two bars of iron of a V shape, one over the other. When rolled together, they would represent a kind of double V, the solid part of the outer bar embracing the joint of the inner coil, and *vice versâ*, so that there was no joint through the metal. Guns might be made upon that principle of any size, from a pistol up to an 80-pounder. Musket, or rifle barrels could be made, either of iron, or steel, on the same principle, by machinery, quite as readily as common barrels, or gas tubes were now made.

With reference to the various forms of guns, which had been noticed, he was prepared to admit, that the plan of shrinking a series of hoops upon an old cast-iron gun, would add considerably to its strength. But he did not think that plan ought to be adopted, in the case of new guns, because they might be made on a cheaper and better method. Notwithstanding the favourable results obtained with a gun on that system, he thought too high an estimate had been entertained of the strength of such a gun. The fact appeared to have been overlooked, that a hoop was weakened just in proportion to the amount of contraction put upon it. He contended, that a hoop in its usual state, was stronger than when it was put into a state of tension. Supposing a weight was lifted 15 feet high, and a hoop was placed underneath, with a tapered mandril in it. If five blows were sufficient to burst the hoop, it would, after it had received one blow, be one-fifth part weaker than it was previously; and he considered, that shrinking a hoop on to a solid body was tantamount to giving it one blow. He knew from experience, that if a hoop was made so small, that it had to be considerably heated, and it was then forced on to its place, it would frequently break by the power of its own contraction. He had no hesitation in saying, that many accidents

on railways had been occasioned by the tyres of the wheels of the carriages having been shrunk on too tight; and when worn, they had not sufficient strength to resist the tension to which they were subjected by the contraction.

Mr. WHITWORTH exhibited a model of his rifled cannon, which he had brought to the Meeting, at the request of the President, through whom a number of questions were addressed by the Members to Mr. Whitworth, who explained, that the metal used in the construction of his guns, was the material called 'homogeneous iron,' which partook largely of the nature of mild steel. It was made chiefly from bars of Swedish iron, cut into short lengths, melted in crucibles, and cast into a large cylindrical ingot, which was subsequently forged, under a tilt hammer, into the required form. The guns were forged solid, bored out in the usual manner, and rifled uniformly throughout their length, without leaving any chamber at the breech end. The pitch of the rifling in a 12-pounder gun was one turn in 60 inches.

The operation of loading was very simple; the breech, which consisted of a screwed cap, suspended in a hinged collar, so as to swing freely to the right hand of the gun, was unscrewed and turned aside, the rifled projectile was introduced, and followed by the metallic case cartridge, with its lubricating wad at the forward end, the breech cap was swung home and screwed up, the fuse was introduced through the centre of the breech, and the gun was fired. This operation was so simple, that great rapidity in firing could be attained, if it was considered desirable.

One of the projectiles exhibited was a 2½-lbs. shot, which had been thrown the distance of 5½ miles, by a charge of 8 oz. of powder, when fired from a small 3-pounder gun, weighing 208 lbs. The gun was fired at an elevation of 35°.

The cartridge used was made of tinned iron, shaped to fit the rifled bore; the powder was retained in it by the lubricating wad, which was placed in the open end. This wad was composed of wax and tallow, and when the explosion took place, it was melted and was driven through the gun, lubricating the bore so thoroughly, that with a good quality of powder, the gun might be fired, for almost any period, without requiring to be cleaned by sponging it out. Some of the projectiles were cast in the proper form, the hexagonal bearing surfaces being cut, or shaped, by self-acting machinery. The cost of shaping a 12-lbs. shot did not exceed the expense of a penny per shot, for wages only. Very long experimental shells had been fired from the 24-pounder guns; and as there was not any chamber in the gun, a large charge of powder and any length of projectile might be used; it was, therefore, easy to try various charges and weights of shot, and thus to find out what was the proper charge of powder and what was the best length of shot for the gun, for a particular object. The 3-pounder

gun would, with a suitable charge of powder, throw a shot weighing $2\frac{1}{2}$ lbs., further than it would throw a projectile weighing 2 lbs., or 3 lbs. A shot weighing $2\frac{1}{2}$ lbs. was, therefore, shown to be the kind of projectile best suited to a gun of $1\frac{1}{2}$ inch calibre. In the same way, the proper weight and form of projectile best suited for the 80-pounder gun, was determined by a series of experiments, which showed that the gun called a 68-pounder, was that best adapted to an 80-lbs. shot. With this weight of projectile the best momentum was obtained, and it was, therefore, the most effective. The various forms of projectiles exhibited, had been arrived at by very careful investigation, and were not the result of *à priori* reasoning alone; they were, in fact, the results of many experiments, and as facts were obtained, further experiments were instituted, and thus the ultimate results were attained. The flat-fronted projectile was a model of that fired through the iron plate, 4 inches thick, and the side of the ship 'Alfred' at Portsmouth, from a distance of 450 yards. That projectile was fired from a cast-iron gun, such as was ordinarily used in the service, except that it was rifled: it was too weak to bear the strain, and it burst the day after the experiment, above referred to, was made. Flat-fronted projectiles weighing 24 lbs. were fired from brass howitzers rifled by Mr. Whitworth in 1856. They were fired during a series of experiments, made by Captain Hewlett on board the 'Excellent.' The shot passed through 30 feet of water diagonally, and 8 inches thickness of oak, piercing the timber 3 feet below the surface of the water, and burying itself many feet in the earth, or mud. This was believed to be the first instance of a shot having passed through water, with such an effect. When spherical shot, or long projectiles, with rounded fronts, were fired into the water, they would not penetrate below the surface, but they turned and came out again. The flat-fronted shot was the best form for traversing iron plates. If the round-fronted form of shot was fired against a thick wrought-iron plate, it displaced the particles of the iron plate, in a lateral direction, and had to overcome the great lateral resistance they offered to its passage. In the case of the flat-fronted shot, the resistance was confined to the exact spot on which the flat front of the shot struck; the resistance was direct and not lateral; and if the momentum of the shot was sufficient, and its particles cohered together, it punched a hole in the plate. In the experiment made on board the 'Excellent,' the gun was depressed, and the shot, fired at an angle, passed through 30 feet of water, striking the oak target and piercing it, 3 feet below the surface. The shot weighed 24 lbs., and the charge of powder was $2\frac{1}{2}$ lbs. The gun was a brass howitzer 52 inches long, such as was used in the service, except that it was rifled. From that

howitzer an experimental shell, 40 inches long, had been fired, which, with the charge of powder, nearly filled the bore of the piece.

In reply to a question relating to the strength of the material used for the rifle, Mr. Whitworth observed, that he had put into a rifle barrel, 1 inch in diameter at the breech, with a bore of 0·49 inch, a leaden plug 18 inches long, as tightly as it could be driven home upon the charge; it was fired with an ordinary charge of powder, and the long leaden plug being expanded by the explosion, remained in the barrel, the gases generated by the gunpowder all passing out through the touch hole, which was small and lined with platina. The lead was then melted out of the barrel, and the same experiment was repeated four times, with the same results. He was, therefore, satisfied, that the homogeneous metal was sufficiently strong, to resist the greatest strain to which, in practice, it could ever be subjected.

Much had been said as to the alleged great cost of the Whitworth rifles. But cost should be considered relatively to the material and workmanship, which should be of the best quality for the best weapons. In the first place, the best material that could be obtained was employed. It cost £60 per ton; it was very hard, very tough, and very difficult to be worked, but then it was very good, very strong, and very durable. It was unreasonable to compare the price of a rifle made of such material, with that of a rifle made of the softer and more easily worked, but far less durable material used at Enfield, for the ordinary service musket. Some time since, Mr. Whitworth had recommended, that rifles should be made, at Enfield, with his bore and twist in rifling, of about two turns in the length of the barrel of 39 inches, or one turn in 20 inches, instead of only half a turn, as in the Enfield rifle. He recommended, that rifles should be made, having that comparatively quick turn and the hexagonal bore of the diameter, which he employed; and he had no doubt whatever, if that had been done, the effectiveness of the rifles would have been doubled, and they would have been made at the same expense. If a rifle was made of a material more expensive and harder to work, it could not be done at the same cost; it would, however, be better, and in reality, it would be more economical, to make a more effective and more durable weapon, as the increased cost would be recovered in the extended wear. Mr. Whitworth stated, that in the competitive trials made before an official Committee, between the Whitworth and the Enfield rifles in April 1857, the results were pretty nearly about three to one in favour of the Whitworth rifle, in accuracy of firing and length of range. A target was made with the Whitworth rifle at 2,000 yards, whilst the longest range of the Enfield rifle was 1,400 yards.

Reverting to cannon, Mr. Whitworth explained, that the 80-

pounder gun was purposely made so strong, that it could be submitted to any proof, without injury. It was made of homogeneous iron. Upon a tube, having an external taper of about 1 inch, a series of hoops, each about 20 inches long, were forced by hydraulic pressure. Experiments enabled him to determine accurately what amount of pressure each hoop would bear. All the hoops were put on with the greatest amount of pressure they would withstand, without being injured. A second series was forced over those first fixed, and thus the 80-pounder gun was constructed. At the present time, it was not necessary to have the second series of hoops, but it was thought better, in the case of the first large rifled cannon, to have it stronger than was practically necessary; in fact, to make it so strong, that gunpowder could not burst it. In the 12-pounder there were not any hoops at all, and Mr. Whitworth believed, that a large-sized gun could be made with this homogeneous metal, without hooping it. The inside of the 80-pounder gun was made of a tube of homogeneous metal; and the external rings were of fibrous iron, except two hoops next to the breech, which were made by Mr. Clay of puddled steel. The hoops were put on cold. The rifle twist in the 80-pounder gun was one turn in 100 inches; in the 12-pounder it was one turn in 60 inches; and in the small 3-pounder, it was one turn in 40 inches. With respect to the degree of rifling adopted in the Whitworth guns, enabling the powder to be consumed more effectually, the following experiment was mentioned. Two barrels alike in diameter and bore were prepared; all the conditions were identical, except the difference of twist in the rifling. One barrel had two turns, and the other had four turns. It was found, on placing them both at an elevation of 1° 20′, and firing them with 50 grains of powder, that they each carried the shot to about the same height on the target. Mr. Whitworth then fired them with an increased charge of powder, and the barrel with two turns sent the shot considerably higher upon the target, while the barrel with four turns sent its shot but very little higher than with the small charge. A length of 10 inches was then cut off the latter barrel, leaving only three turns, and it was fired again with the increased charge. The result was, that, the elevation remaining the same, it threw its shot higher on the target, than the other barrel. This showed, that rotation must bear a due proportion to the length of the barrel. It was desirable to have as much rotation as possible, taking into consideration the length of the gun. With a very long gun, it was not advisable to have very rapid rotation, as the quick turn of the projectile was most felt at the muzzle.

It was further explained, that the experiments of which Mr. Whitworth had spoken, were made at Portsmouth, against the side of the ship 'Alfred,' covered with iron plates 4 inches thick. At a range of 450 yards, the shot traversed the iron plate, and also

pierced the side of the ship on which it was bolted; the shot was picked up inside the vessel. Experiments were about to be made, to try whether with the Whitworth 80-pounder gun, the flat-fronted shot would traverse the wrought-iron plates, 4½ inches in thickness.

Mr. Wheatley remarked, that in the course of experiments in the United States, it was found, that round shot glanced off the target at an angle of 15°. He thought it very likely, that Mr. Whitworth's shot would rip open a plate at that angle. It would be worth while to try the experiment.

Mr. Conybeare inquired, whether Mr. Whitworth had not found, that an increased twist, increased the tendency of the shot to be thrown on one side of the line of fire. Rifles, when fired from fixed rests, did not throw the shot in one line of sight, but either to the right hand, or to the left, according to the rifling. The French had reduced their rifling, in order to get rid of the amount of divergence.

Mr. Whitworth said the shots did diverge in the direction in which the barrel was rifled; but there was no practical difficulty in the matter, as the deviation could be easily allowed for in sighting the gun. In the long ranges, very much depended upon the influence of the wind. Sometimes it would carry the shot 200 feet to the left; at other times 400 feet to the right, from the line of fire, supposing that no allowance was made for it.

The value of the self-acting machinery for shaping the rifled-cannon projectiles, would be about £500, to enable a workman to produce the shot at such a rate, as that the cost should not exceed one penny per shot, for wages only.

Mr. Bidder,—President,—remarked, it was a most material point that, continuing to use the same material, a service rifle might be made at Enfield, upon Mr. Whitworth's principle of rifling and loading, at about the same cost as that at which the Enfield rifles were now supplied. He understood that to be the opinion of Mr. Whitworth. He also presumed, that Mr. Whitworth still retained the opinion, that the bore he adopted for his rifle, was better than that which had been selected for the Enfield rifle.

Mr. Whitworth replied, that his opinion was founded upon experiments, which showed that the diameter of bore he used, was more suitable for ordinary men than a larger bore, and for this reason;—if men were by nature three times stronger than they actually were, then the bore of the Enfield rifle would be right. There was for each bore a proper charge, to give the best trajectory; the charge that would give the best trajectory with the Enfield bore, would be far too great, and would produce too much recoil, for a man to bear. He had, therefore, adopted a bore so reduced, that the proper charge for it would only produce such a recoil, as was not too great for a man to bear.

Captain W. S. Moorsom said, it seemed to him, that the observa-

tions, as to the size of the bore which especially affected the soldier, touched upon the line of demarcation which should be drawn between the Civil Engineer and those whose business it was to use these weapons; and he should like to know, how far it might be considered as trenching upon a subject, which could hardly be supposed to be properly understood by the Members of the Institution. It was to be borne in mind, that at a recent period in the military history of this country, one of the most valuable corps in the service could not fire twenty rounds continuously from the shoulder, without being put 'hors de combat,' in consequence of the improper construction of the arm used. He was by no means prepared to say, that it was within the province of the Civil Engineer to discuss that question. It struck him as being singular, that whereas it had been said by one who, he was told, was a scientific and practical man, and who was placed at the head of one of the largest establishments of the Government, that this subject could only be handled by practical Officers of Artillery; yet after that preamble, not a single practical fact had been adduced, by that gentleman, to illustrate the question under discussion, or to throw any additional light upon it. If, therefore, there was anything which showed the necessity, and the judiciousness of carrying out the suggestion of the President, that in the present Session, subjects of the most vital importance to the country should be entertained, in a way which belonged only to this Institution, not as going beyond what they knew as Civil Engineers, it was afforded by the circumstance to which he had alluded. He thought the President, and the Members of the Institution generally, had already conferred great benefit upon the country, and would continue to do so, by handling these subjects, with mutual temper, forbearance, and knowledge; so as to bring the military and the civil services into the best possible combination, for the improvement of the national resources and defences. There was now present one of the most practical Officers of the Musketry Instruction of the Army, and he hoped General Hay would give his opinion to the meeting, on the reduction of the bore proposed by Mr. Whitworth.

General Hay remarked, that the trials he had made had been, to a great extent, of a private character; and he was not at liberty to divulge the exact issue of those experiments. But, if he was called upon to give an opinion, as to the relative merits of the Enfield and the Whitworth rifles, that was a matter upon which any man, who had carefully considered the subject, was competent to come to a conclusion. The small bore would of course, in accurate shooting, beat the large bore. There was a peculiarity about the Whitworth small-bore rifles which no other similar arms had yet produced; they not only gave greater accuracy of firing, but treble power of penetration. For special purposes,

any description of bullet could be used, from lead to steel. The Whitworth rifle, with a bullet composed of one-tenth of tin, penetrated thirty-five planks; whereas the Enfield rifle, with which a soft bullet was necessary, only penetrated twelve planks. He had found, that at a range of 800 yards, the velocity added to the hardened bullet gave a power of penetration, in the proportion of 17 to 4, in favour of the Whitworth rifle. Velocity might be taken as a certain test, *cæteris paribus*, of penetration. The penetration of the Whitworth rifle was enormous, and this in a military weapon was of the highest importance, in firing through sand bags, gabions, etc. The Whitworth projectile would penetrate through a sand bag and a-half, or through a three-feet gabion; whereas the Enfield would only go through one bag, or would only reach the middle of a gabion. He thought the merits of the small bore had not yet been sufficiently understood. He was quite aware that it had been stated recently, that the small-bore Enfield had beaten the small-bore Whitworth; but nothing of the kind had ever taken place. Hitherto, the subject, he did not hesitate to say, had been entirely misunderstood, and it was only by such discussions as these, that the public could learn the real facts of the case. It was proper also to state, that the exact bore of the Whitworth rifle had been adopted at Enfield, without acknowledgment; that even the same twist had been given to the rifling, 1 turn in 20 inches; and therefore, it would not be very remarkable, if the same accuracy of fire was obtained. But he had shown, that there were other things to be considered besides accuracy. Supposing, for instance, that the same accuracy of fire was obtained with the small-bore Enfield, as with the Whitworth rifle, there was still the fact of the penetration of the latter being two-thirds more than that of the former. These points were not sufficiently considered. Mr. Whitworth had solved the problem he undertook,—how to project, to the best advantage, a given quantity of lead with a given quantity of gunpowder; and there was no gun in England, at this moment, which would fulfil that condition to the same extent as the Whitworth rifle.

In reply to a question from the President, General Hay said, every gun, in which a certain amount of powder was exploded, would become foul. But if the bullet expanded properly, it left the gun, as it were, sponged out, after every shot. Should the bullet not expand, the gun, of course, would not be sponged out. He ventured to say, that the Whitworth small-bore rifle, fired with common sporting powder, would never foul, so as to render loading difficult. If the lubrication was correct, there could not be any such fouling, even when the rifle was used constantly for a month. He had himself fired one hundred rounds one day, sixty rounds the next, then forty rounds, and so on, and left the gun without being cleaned for

ten days, when it fired as well as it did on the first day. But if the conditions, here insisted on, could not be carried out; if it was intended that bullets should be fired, without proper expansion and lubrication, then fouling would take place and accumulate in any gun. It had been asserted, that the Whitworth small-bore must of necessity foul, because that diameter of bore could not consume 70 grains of powder; but it was well known, that it had consumed 100 grains of powder with advantage. He had great pleasure in thus bearing his testimony to the merits of Mr. Whitworth's invention.

Colonel EARDLEY WILMOT, R.A., said, there was one remark in the Paper, the precise meaning of which it was difficult to understand. He apprehended, however, that the Author intended to convey the impression, that the Select Committee on Ordnance had treated his invention with contempt. He would just remark, that the Government had added to that Committee a Civil Engineer, Mr. C. H. Gregory, (V.P. Inst. C.E.,) a very proper compliment to the civil engineering profession; Professor Wheatstone; and one of the most distinguished mathematicians in Europe, Professor Sylvester. It was not correct to say, that the principle advocated by the Author was pronounced defective. The experiment, or practice, was certainly found to be so, for by firing the gun with a charge much less, he believed, than an ordinary cast-iron gun of the same size would have been tested with, the breech was blown out, and the wire uncoiled. The original objection taken to this arrangement, was the difficulty of making a sound breech in a wire gun; and also that if the gun were struck by a shot, it would, probably, be rendered unserviceable, owing to the cutting of the wire, or at all events, the extreme accuracy of tension, said to be necessary, would be affected. There was no reason, perhaps, why guns should not be made upon that plan; and it might be the case, that the Author had improved his gun, and had been more successful on each of those two points than formerly. The difficulty of securing the breech was very great. When a certain number of rounds had been fired from Captain Blakely's gun, (Fig. 9, page 304,) the breech was blown out. That would be a difficulty with all muzzle-loading built-up guns; but with breech loaders it would be more simple. He had witnessed the first experiments with the Whitworth gun, and could bear his testimony to the remarkable power of the howitzer gun, which had been mentioned. He had also been present at the early experiments with the Armstrong gun, at Newcastle. The accuracy of the firing was as remarkable then, as it was at the present time. At a distance of 1,500 yards, he could stand within 20 yards of the target, without cover, with perfect confidence. That gun was not now made of the same material, nor in the same manner; the rifling was different, and the form as well as the mode of manufacture of the shot, to what was then the case; so also,

Mr. Whitworth now appeared with a breech-loading gun of a different material. If Mr. Longridge had made modifications in his gun, in like manner, and if it was brought forward in a tangible form, Colonel Wilmot had no doubt it would meet with as much attention as the guns of Sir W. Armstrong and Mr. Whitworth. In regard to cost, in the days he spoke of, money was not so plentiful as it was now. The charge for Sir W. Armstrong's gun, in the first instance was, he thought, £850, and £400 for personal expenses, of which only one-half was asked to be paid. It was now stated, that a larger gun could be turned out complete for a much smaller sum. In reference to the material of which guns should be composed, he knew that many minds were directed to the subject, and he was satisfied that, before long, a good result would be obtained. At the same time, he thought it was a pity, that any conclusion should yet be arrived at, as to the absolute unfitness of cast iron for guns. At the present moment, experiments were being made in Woolwich Arsenal, with a gun which had stood the following discharges; 10 rounds with a cylinder weighing 68 lbs.; 10 rounds with a cylinder weighing twice 68 lbs.; 10 rounds with a cylinder weighing three times 68 lbs.; and so on to four times, five times, six times, and seven times, so that the weight of the cylinder with the last 10 rounds was 476 lbs.; the charge of powder being in all cases 16 lbs.; yet the gun was uninjured. Five rounds had since been fired, with the same charge of powder, and a cylinder weighing 544 lbs., which had the effect of destroying the carriage of the gun. This was repaired, and another round was fired of the same proportions of charge and weight of cylinder, when the gun burst.

He had been furnished with the results of experiments made with a Spanish cast metal 32-pounder, 8 feet 9 inches long, and weighing 45 cwt. That gun was fired, first with 21 lbs. of powder, 2 shots, and 2 wads; then with 9 lbs. of powder, 2 shots, and 3 wads, at an elevation of 10°. He need hardly say, that as the elevation was increased, the strain upon the gun became greater. It was then fired 827 times without injury, with 9 lbs. of powder, 2 shots, and 3 wads; next with 9 lbs. of powder, 3 shots, and 2 wads; then with 9 lbs. of powder, 4 shots, and 2 wads; continuing with the same charge of powder, and the same number of wads, up to 11 and 12 shots, when the gun was full to the muzzle. Subsequently, it was tried with 12 lbs. of powder and 10 shots; 15 lbs. of powder and 9 shots; 18 lbs. of powder and 8 shots; 21 lbs. of powder and 7 shots; 24 lbs. of powder and 6 shots; 27 lbs. of powder and 5 shots, when the gun was again filled to the muzzle, and then it burst. It thus took, to burst that gun, an aggregate of 3 tons 13 cwt. of powder, 25 tons 8 cwt. of shot, and 2 tons 19 cwt. of wads.

An American shell-gun, 9 feet long, 9 inches in diameter, and weighing 81¼ cwt., had been fired with the following results:—

Number of Rounds.	Charge of Powder.	Number of Shot and Shell.	Weight of Shot and Shell.
	lbs.		
2	15	1 shot	90
1,500	10	1 shell	72
5	15	1 shot	90
5	15	2 shot	180
2	15	3 shot	270
3	15	4 shell	288
1	20	3 shot, 1 shell	342
1	20	2 shot, 4 shell	468
1	20	2 shot, 6 shell	612
1	20	7 shot	630
1	20	8 shot	720
1	20	9 shot	810
1	20	10 shot	900

When the gun burst.

He might also mention, that a British 32-pounder was known to have fired, at the siege of Sevastopol, three thousand rounds; and though the vent was much enlarged, the bore was perfectly smooth, sound, and serviceable.

If cast-iron guns could be made to withstand such a test, they should not be altogether discarded. He did not mean to say, that cast iron was the proper material for rifled cannon, but simply, that it was a metal which was not unworthy of consideration. It might be supposed, from the remarks he had made, that he was an advocate for cast-metal guns. For economy and simplicity of manufacture, a cast metal was preferable to a wrought one. He certainly saw no reason to despise even cast-iron guns, although several guns which he had made had burst, and others very lately, which he knew would burst, and had put aside as unworthy. It was for the purpose of improving the character of cast iron,—not eventually excluding steel,—that the Royal Gun Foundry, at Woolwich, had been established. It was not proposed to stop the operations of private firms; but to make experiments, in order to arrive at a certain method of making guns, so that the work, which this description of gun had been known to do, might be relied on. Although that establishment was commenced, without the means of getting information from those who were capable of giving it, but had to be worked out, step by step, he was nevertheless satisfied, that it would have accomplished its purpose successfully and satisfactorily. He made this remark, because he considered that establishment was not a Government work only, but a national undertaking, about which there should be no misunderstanding. All were equally interested, in finding out, if it was possible, how to make cast-iron guns possessing all the qualities which were required.

Allusion had been made to the rifling of the old service guns. The use of elongated projectiles increased the strain upon the guns, but not to the enormous extent which had been supposed, because the charge of powder was proportionately diminished. It had been said, that if the windage was diminished, the strain upon the gun would be increased. That might be true to a limited extent. The great injury in firing round-shot guns was from the windage. If the shot was made completely to fit the gun, it might be fired repeatedly without injury, as there would then be an absence of the bounding motion of the shot, whilst passing through it. He believed, in such cases as those brought forward by Mr. Britten, that with shot weighing from 50 lbs. to 55 lbs., and the windage prevented by a soft material like lead, it was not a necessary consequence, that the gun should burst with the charge requisite to get a good result. The old service guns might, he thought, be easily rifled for ordinary use, and be then as good as most of the foreign rifled guns.

A statement had lately been made relative to brass guns. It was wished to ascertain, whether brass guns might be used either as muzzle-loaders, or as breech-loaders; and whether the action of the iron projectile would have an injurious effect upon the brass. In actual trials, no injurious impression seemed to be made; indeed, as far as was at present known, a rifled cannon could be cast of brass, as well as of any other material, and with soft metal shot, it would last for a long time. It had also been stated, that such a gun would only stand eight hundred rounds, and had then to be disposed of for one-half its value. This was not the case. Brass guns were re-melted into new ones; and this metal possessed the advantage of being capable of conversion into any new form required. A brass gun was lately fired more than eleven hundred rounds, with a slightly diminished windage, and was still perfectly fit for service. Time, labour, and influence were required, to put this subject on a proper footing. He felt convinced, that whatever was done for the service of the country, would be duly considered, with proper regard to the public good.

Mr. Whitworth stated, with respect to the brass guns spoken of, that they had been rifled for the Government at the request of the late Lord Hardinge, in 1856, and upon exactly the same principle as he now adopted. They only differed from the guns fired during the late experiments, in being muzzle-loaders. It was a pity that they, and similarly-rifled brass guns, had not been employed, as they might have been, on actual service, in India and China. By means of the lubricating wad, all difficulty arising from the fouling was obviated, and if those brass rifled guns were mounted on proper carriages, and provided with proper sights, they would, probably, give as good results as any he had hitherto obtained from his breech-loading guns.

Sir WILLIAM ARMSTRONG said, the subject of the present discussion was one upon which he had hitherto observed almost entire silence, and it was only because the public attention had recently been so vigorously roused, in reference to competing systems of gunnery, that he was induced to deviate from that reserve, which it would have been more consistent with his official position to have maintained. It was, however, a satisfaction to him, that owing to existing circumstances, the first distinct and detailed description of his rifled ordnance and projectiles, would be communicated to an Institution composed of his professional brethren, and comprising so many persons with whom he had long been on terms of intimacy and friendship.

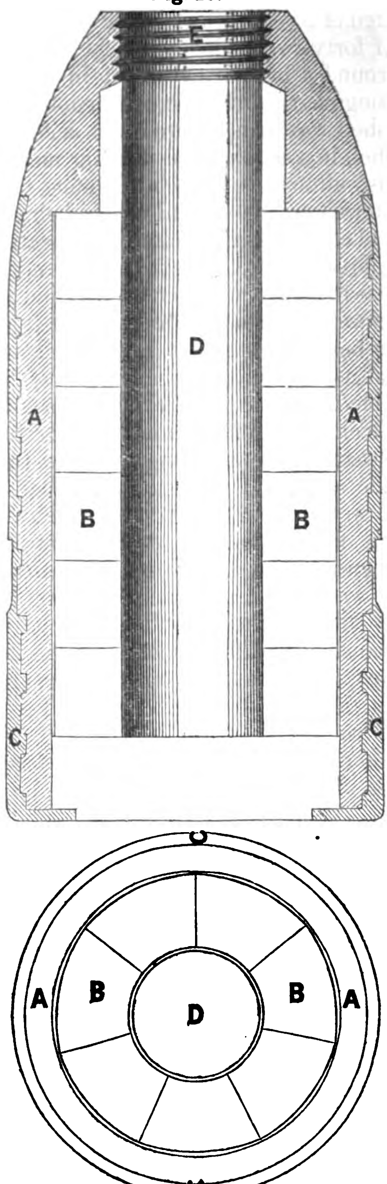
He had brought, for inspection, a specimen of his 12-pounder field gun, in the exact form in which it had been recently introduced into Her Majesty's service. But before he proceeded to give a description of it, he thought it would better conduce to a clear understanding of the gun, if he first directed his observations to the projectile; because he considered, that in all cases, the projectile should rule the gun, and not the gun the projectile. The projectile had to do the work, and it must, evidently, be the proper course, first to determine what kind of projectile was required, and then to devise the form of gun most suitable for throwing it.

It had, hitherto, been the practice to take into the field, three kinds of projectiles, viz.:—

1st. Solid round shot;
2nd. Shrapnel shell;
3rd. Canister shot.

The first of these was, as its name implied, a simple solid sphere of cast iron. The second was a shell, containing leaden bullets, with a small bursting charge; and fitted with a time fuze, ignited by the flash in the gun, so as to explode the shell a short distance in front of the object aimed at. The third consisted of a number of small iron balls, enclosed in a thin canister, and designed for firing upon an enemy, at very short distances. Both the round shot and the shell were very uncertain in their action, and could scarcely be used with effect, at more than a thousand yards. But apart from the defects of all these projectiles, there was an obvious inconvenience in having three varieties to carry, because, after exhausting the kind most suitable for any particular service, it became necessary to resort to a kind not adapted for the purpose. Sir W. Armstrong, therefore, conceived the idea of constructing a projectile, which might be used, at pleasure, as solid shot, as shrapnel shell, or as canister shot; and which should also have the advantage of exploding by impact, as well as by the action of a time fuze. Specimens of this projectile, both entire, and broken

Fig. 28.



12-Pounder Segment Shell.

A A. The Cast-iron Case, or Shell.
B B. The Segment Shot in layers.
C C. The Lead Covering.
D. The Central Cavity for the Bursting Tube and Concussion Fuze.
E. The Screw for the Time Fuze.

open to show the interior, were exhibited. (Fig. 28, page 408.) The projectile consisted of a very thin cast-iron shell, the interior of which was composed of forty-two segment-shaped pieces of cast iron, built up in layers around a cylindrical cavity in the centre, which contained the bursting charge, and the concussion arrangement. The exterior of the shell was thinly coated with lead, which was applied by placing the shell in a mould, and pouring melted lead around it. The lead was also allowed to percolate among the segments, so as to fill up the interstices, the central cavity being kept open by the insertion of a steel core. In this state the projectile was so compact, that it might be fired through 6 feet of hard timber, without injury; while its resistance to a bursting force was so small, that less than one ounce of powder was sufficient to break it in pieces. When this projectile was to be used as a shot, it required no preparation, but the expediency of using it in any case, otherwise than as a shell, was much to be doubted. To make it available as a shell, the bursting tube, the concussion arrangement, and the time fuze, were all to be inserted; the bursting tube entering first and the time fuze being screwed in at the apex. If then, the time fuze was correctly adjusted, the shell would burst, when it reached within a few yards of the object; or failing that, it would burst by the concussion arrangement, when it struck the object, or grazed the ground near it. Again, if it was to act as 'canister,' upon an enemy close to the gun, the regulator of the time fuze must be turned to zero on the scale, and the shell would then burst at the instant of quitting the gun. In every case the shell, on bursting, spread into a cloud of pieces, each having a forward velocity equal to that of the shell, at the instant of fracture.

One of these shells had been burst in a closed chamber, where the pieces could be collected. It would be seen that they consisted of:—

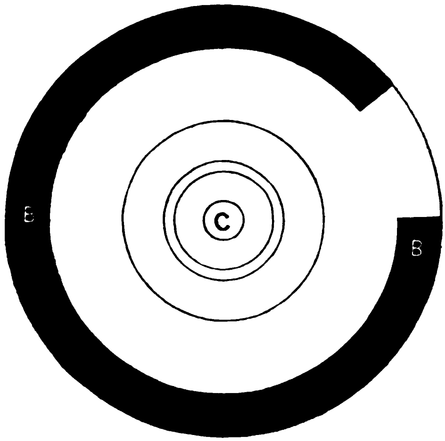
106 pieces of cast iron;—99 pieces of lead;—and 12 pieces of fuze, &c.; making in all 217 pieces.

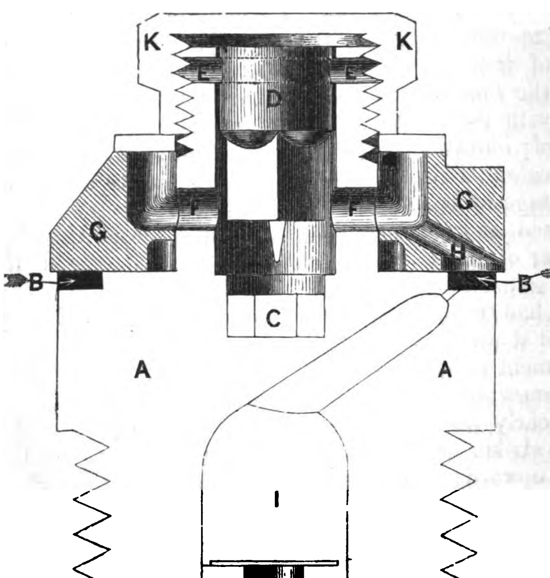
Now it was no uncommon thing for one of these shells to make 100 holes in a column of targets, at a distance of 3,000 yards, and as a large proportion of the pieces was derived from the lead, it would be seen, that the lead added greatly to the efficiency of the shell.

The time fuze and the concussion arrangement demanded careful explanation.

The body of the time fuze, (Fig. 29, page 409,) was made of a mixture of lead and tin, cast to the required form, in a mould. The fuze composition was stamped into a channel, forming nearly an entire circle round the body of the fuze, and was afterwards papered and varnished on the external surfaces. As the shell fitted accurately into the gun, there was no passage of flame, by which the fuze could be ignited. That effect was, therefore, produced in the fol-

Fig. 29.



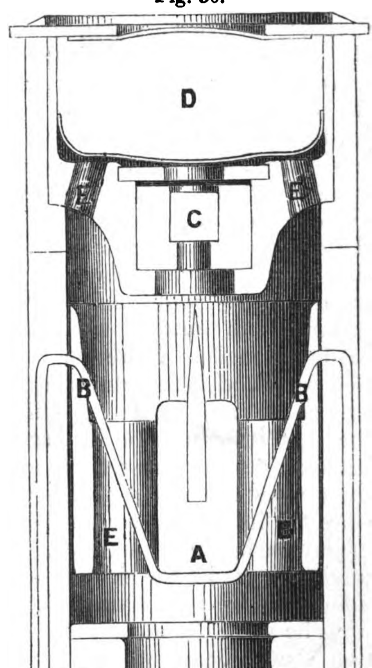


Time Fuze.

A A. The Body of the Fuze.
B B. The Groove containing the Fuze Composition.
C. The Detonator.
D. The Striker.
E E. The Holding Pin.
F F. The Flame Passage.
G G. The Revolving Cover, or Regulator.
H. The Igniting Aperture.
I. The Chamber for the Priming Powder.
K K. The Tightening Cap.

lowing manner. A small quantity of detonating composition was deposited at the bottom of the cylindrical cavity in the centre of the fuze, and above this was placed a small weight, or striker, terminating in a sharp point presented downwards. This striker was secured in its place by a pin, which when the gun was fired was broken, by reason of the vis inertiæ of the striker. The detonator was then instantly pierced by the point and was thus fired. The flame, thus produced, passed into an annular space, formed within the revolving cover, which rested on the upper surface of the fuze composition, and from this annular space, it was directed outwards, through an opening, so as to impinge on and to ignite the fuze composition, at any required part of the circle. The fuze, thus ignited, burnt in both directions, but only took effect at one extremity, where it communicated with a small magazine of powder in the centre. The fuze was surrounded by a scale paper, graduated to accord with the elevation of the gun, so that when the range of a distant object was found by trial, it was only necessary to turn the igniting aperture of the cover, to the point on the fuze scale, corresponding with the degrees and minutes of elevation on the tangent scale. This fuze had the advantage of being capable of adjustment and re-adjustment any number of times, before entering the gun, and the officer in command, had the opportunity of seeing that it was correctly set, at the moment of being used.

Fig. 30.



Concussion Fuze.

A. The Striker.
B B. The Holding Wire.
C. The Detonator.
D. The Chamber for the Priming Powder.
E E. The Flame Passages.

The concussion fuze, (Fig. 30,) was on nearly the same principle. A striker with a point, presented upwards, was secured in a tube by a wire fastening, which was broken on the firing of the gun; the striker being then liberated, receded through a small space, and rested at the bottom of the tube, but as soon as the shell met with any check in its motion, the striker ran forward and pierced the detonator in front, by which means, the bursting charge was ignited.

It would be seen, that the projectile, when thus complete, with its time fuze attached, was far from being of that form and proportion which ought to be selected, if length of range were the only consideration. Comparisons, therefore, ought not to be drawn between a shell thus designed for effect, and a solid shot designed for range. Its range, however, was enormous, in comparison with that of round shot, and as far as could be collected from the published reports of Mr. Whitworth's practice, it was not much short of that obtained with his 12-pounder projectile, when equal charges were used. It would be absurd, however, to contend that the form of this shell should be modified, at the expense of its efficiency, merely to obtain a small increase of range, when all military authorities agreed, that the range already attained was even more than sufficient for all field operations.

The public was always captivated by the attainment of long ranges; but great delusion prevailed on that subject. To hit an object upon a measured range where the distance was accurately known, was a very different matter from hitting the same object in the open country, where the distance had to be discovered. At 4,000 yards, a man on horseback, (taking man and horse as one object,) subtended an angle of less than 3 minutes of a degree, and 3 minutes of elevation was equivalent to only 15 yards in range. Hence therefore, assuming the gun to be absolutely perfect, unless the distance could be determined to such a nicety as 15 yards, a shot would either fall short of, or go over the object. But so far from its being possible, by any available means, to determine the distance with such precision, an error of even 500 yards might easily be made. Moreover, the variation of atmospheric refraction would, at such a distance, generally falsify the elevation, to a very embarrassing extent; whilst the wind blowing with, or against the shot introduced a further complication, in itself sufficient to baffle all attempts at refined adjustment of the angle. Even trial shots were unavailing to determine elevations for long distances, since the intervals between the graze and the object could not be appreciated. The fact was, that however perfect the weapons might be made, the fate of a battle would never be materially influenced by very distant firing. The real struggle would always lie within a distance of 2,000 yards, and the first consideration should be, to make the weapons as destructive as possible within that limit. As to firing solid bolts, at an elevation of 35°, in order that they might fall amongst an enemy five miles distant, it would be mere waste of ammunition. Certainly what went up, must come down, but according to the doctrine of probabilities, and to all experience of what was called 'vertical fire,' the chance of any one being injured by a projectile falling, as it were, from the clouds, was too remote to be worth consideration.

The gun was composed wholly of wrought iron, and the prominent feature in its manufacture was the application of the material in the form of long bars, which were coiled into spiral tubes, and then welded by forging. For the convenience of manufacture, these tubes were made in lengths of from 2 feet to 3 feet, which were united together, when necessary, by welded joints. From the muzzle to the trunnions, the gun was made in one thickness, and was, therefore, so far as that portion was concerned, strictly analogous to the barrel of a fowling-piece. Behind the trunnions two additional layers of material were applied. The external layer consisted, like the inner tube, of spiral coils, but the intermediate layer was composed of iron slabs bent into a cylindrical form and welded at the edges. The reason for this distinction was, that the intermediate layer had chiefly to sustain the thrust on the breech, and it was, therefore, desirable, that the fibre of the iron should be in the direction of the length, while elsewhere in the gun, it was more advantageously applied in the transverse direction. The back end of the gun received the breech screw, which pressed against a movable plug, or stopper, for closing the bore. This screw was hollow, and when the stopper was removed, the passage through the screw might be regarded as a prolongation of the bore. The screw was turned by means of a handle, which was free to move through half a circle, before it began to turn the screw. It had thus a certain amount of run, which enabled it to act as a hammer, both in tightening and slackening the screw. The bore was 3 inches in diameter, and it was rifled with thirty-four small grooves, having the driving side rectangular and radial, and the opposite side rounded. The bore was widened at the breech end $\frac{1}{8}$th of an inch, so that the shot might enter freely, and choke at the commencement of the grooves.

The sights were peculiar. The eye hole of the tangent sight was in the form of a cross, which admitted of the vertical and horizontal adjustment being determined with great accuracy. There was a traversing movement at the top, to give correction for a side wind, as well as for the constant deviation to the right, which affected rifled projectiles of nearly all shapes, in a greater, or less degree. A vernier was applied both to the vertical and the horizontal scale, to enable the elevation and the correction to be adjusted to minutes of a degree. This tangent sight was designed chiefly for long distances, where great deliberation could be used, in adjusting the gun; but for rapid firing, at close quarters, a simpler and readier sight was provided. In this the elevation was given in short steps, each corresponding with 50 yards in range, and defined by a ratchet action, which indicated the successive steps by a very audible click.

The process of loading was effected by placing the projectile, with the cartridge and a greased wad, in the hollow of the breech screw, and thrusting them either separately, or collectively, by a

rammer, into the bore. The stopper was then dropped into its place and secured by half a turn of the screw. The gun was fired by the ordinary friction tube, the vent being contained in the stopper. It would be seen, that the whole operation was simple, and could be very rapidly performed.

In the early guns, it was necessary, that the portion of the bore which was occupied by the shot, should be perfectly clean, otherwise, the shot would not always enter its place. A wet sponge had, therefore, to be used; but in the new guns, now issued for service, a slight alteration in the bore had enabled a greased wad to be employed with perfect effect, in substitution of the wet sponge. The gun could now be fired with great rapidity, and apparently, for any length of time, without being sponged at all.

The reason for making the vent in the stopper was, that since the chief wear of a gun always took place at the vent, it was better to make it in a part which could be easily replaced, than in the body of the gun itself.

The breech screw, being internal, was never exposed to injury, nor could drifting sand, or dust, ever reach the oiled surfaces, so as to impede the action of the screw, by adhering to the lubrication.

The screw was of small diameter, and the few inches of extra length in the gun, required for its reception, could not be of any importance, considering that any further reduction of weight was prohibited by recoil.

The stopper had been secured from falling by a chain, but in practice, it was preferred to leave it loose. The man who fired the gun, lifted the stopper after each round, and in so doing, only occupied time that would otherwise be vacant. A duplicate stopper accompanied each gun.

The form of carriage, which was originally used, was represented by the model exhibited. It was fitted with a recoil slide, which was afterwards abandoned for field guns; but it was now decided that the principle should be retained in the ship guns. It was a point of great importance, that a breech-loading gun should be self-acting, in recovering its position after recoil, so as to obviate the employment of so many men to run out the gun. A traversing movement had been originally applied to the field carriages, as shown in the model, and was found to afford great facility in laying the gun. A very neat modification of this traversing movement had recently been contrived in the Royal Carriage Department, and adopted for the field carriages.

Referring to heavy artillery, it was necessary to commence, as before, by considering what effects were required to be produced, and what species of projectile would best answer the purpose. For destroying ships, stone and brick forts, earthworks, and buildings, as well as for operating against hostile troops, it must be admitted, that the shell was the most effective projectile. In

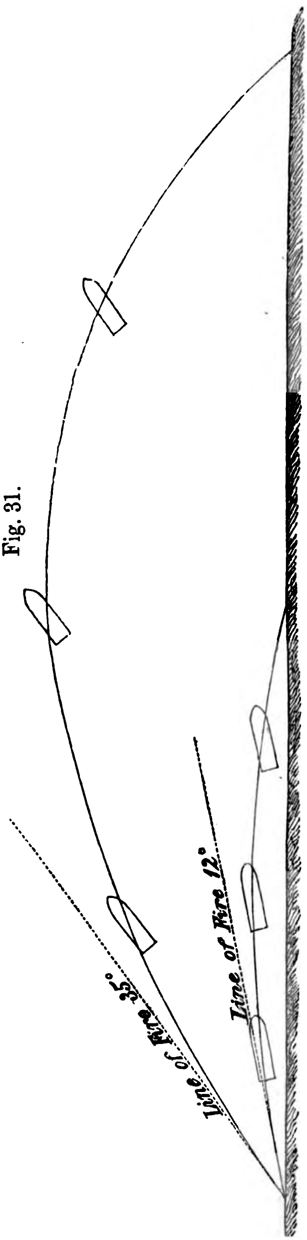


Fig. 31.

Approximate Trajectories of Rifled Shot, fired at 35° and 12°.

fact, with the exception of iron-plated ships and granite batteries, there was nothing that could not be more effectually attacked by shell, than by shot. This must be evident, when it was considered, that a shell, arranged to act concussively, always penetrated before it burst. It, therefore, produced the effect of a shot, before it acted as a shell, and its explosive effect was superadded to that of a shot. Moreover, for high angle firing, the shell was the only projectile to be considered. But the power of a shell depended upon the magnitude of its bursting charge, and a large bursting charge involved a large diameter. It was in vain to say, that increase of length would compensate for smallness of diameter. If a shell for a small bore, could be lengthened, so could a shell for a large bore. Length for length, or weight for weight, the large diameter must, necessarily, accommodate a larger bursting charge, than the small diameter. In the construction, therefore, of heavy guns, Sir W. Armstrong, in contrast with Mr. Whitworth, inclined to the larger diameters, although by so doing, he might sacrifice somewhat in range.

Here it was necessary to say a few words respecting the conditions, upon which the attainment of long range chiefly depended. Everybody would understand, that a long taper projectile would cleave the air more freely, than one of short obtuse proportions; but there was another condition, not generally recognised, which had also a most important influence; viz., the sustaining effect of the air, consequent upon the obliquity of the shot to the path of its flight. It would be seen by reference to the diagram, (Fig. 31,) that since the axis of the projectile in its flight remained

parallel with its original direction, it constantly acquired an increasing obliquity to the direction of its flight. Hence, therefore, the air acting on the inclined surface presented by the under side of the projectile, pressed it upwards like a kite, and although the shot was not actually lifted, its descent was retarded, and it had, therefore, time to reach to a greater distance, than it would otherwise attain. It would be observed, that this sustaining action was chiefly operative at low angles. At high angles the shot would, eventually, become transverse to the curve, and the lifting action would then cease. Sir W. Armstrong had long since pointed out, though he never did so without meeting with incredulity, that owing to this buoyant influence, a lengthened projectile from a rifled gun, actually attained at low angles, a greater range in a resisting atmosphere, than it would 'in vacuo.' This he knew to be the case, with some of his own projectiles, and he had no doubt, that any one who would investigate the matter, would find that the same effect was produced with Mr. Whitworth's projectile also. It was very generally supposed, that the axis of the projectile did not thus preserve its parallelism, but that it continued to move throughout its course, with its point in the direction of the curve. It was impossible, however, to reconcile the observed phenomena of the case, with such a supposition, nor was it possible to conceive, that any sympathy could exist between the direction of the axis, and the curve of the flight. Experiments had been quoted, of rifled projectiles having been fired with such small charges, as to allow of the projectile being distinctly seen in its course through the air, and it was said to have been clearly perceived, in such cases, that the axis followed the curve; but in all Sir W. Armstrong's own experiments, the indications attending the graze marks, and the form of the holes made in distant targets, led to a contrary conclusion. In fact, it was easy to understand, that the eye might be deceived, by the impression left on the retina, by an object thus rapidly moving, and producing the illusion of a sort of tail following the direction of the curve.

The slight difference in range, between a small bolt and a large one, was another circumstance, which could only be explained upon the assumption of the axis being diagonal to the curve. Although the longer time of flight, in the case of the smaller projectile, indicated a much less sustained velocity, yet the distance reached was almost identical. This could only be accounted for, by the larger proportion of surface in the smaller bolt, and the greater floatation, (as it might be called,) due to that surface. But that species of floatation implied obliquity, and could not have any existence without it.

The constant deviation to the right, was also in accordance with what had been stated. Owing to the obliquity of the shot, the

air would operate with more effect, in its upward pressure, upon the tapered front, than upon the back, and any tendency to raise one extremity of the axis of a rotating body, resulted in a lateral deflection, as was exhibited in the gyroscope. This cause of the deviation had already been pointed out by Dr. Magnus, a Continental writer, whose conclusions were now generally concurred in.

Now in applying this reasoning to the question of diameter of bore, it would be seen, that although a solid cylinder of small diameter, had a decided advantage, as regarded penetration of the air, over a hollow cylinder of large diameter, yet the hollow cylinder had the advantage in floatation, and the consequence was, that the difference in range was not nearly so considerable as might, otherwise, be supposed.

After a full and careful consideration of all the bearings of the case, Sir W. Armstrong had come to the conclusion, that a bore of 7 inches was about the most generally advantageous, for a 100-pounder gun, not only in reference to the shell, but also as regarded the solid projectile; because a shot of large diameter, by making a larger hole and producing more splinters and greater displacement, was, in general, more efficacious, than a long narrow bolt. A specimen of the cast-iron shell designed for the 100-pounder gun was exhibited. It was cast very thick, in order that it might bear violent impact, without premature fracture, for when a shell broke on striking, the force of the explosion was almost entirely lost. In its present form it contained upwards of 8 lbs. of powder, but if it was cast thinner and longer, the charge could be increased to 12 lbs. The fuze which was used with this shell, was one on the concussion principle, but it differed materially from that which had been already described. From what had been stated, it would be inferred, that a cylindrical shell; fired at a high angle, would fall upon its side, and the fuse must, therefore, be arranged to take effect, whether the blow was upon the point, or on the side.

It was, also, proposed to use for the 100-pounder gun, a built-up shell, similar to that already explained, in connection with the field gun, and this shell, when used against ships so as to burst concussively the instant it had passed through the side, would, probably, be the most formidable projectile ever used in naval warfare.

Although a bore of 7 inches had been adopted for the 100-pounder gun, it might be desirable, for special purposes, when extreme penetrating power was required, to employ a gun of smaller bore. It was manifest, for example, that a shot of 100 lbs. in weight, which delivered its blow upon an area of 20 superficial inches, would exert a greater punching effect, than one that operated upon double that area. A small bore was, therefore, obviously the right thing for piercing thick iron plates, pro-

vided shot of steel, or homogeneous iron were used, but it remained to be seen, whether the expense of such projectiles would not almost prohibit their use. Mr. Whitworth had fallen into an involuntary error, by stating that a shot from one of his guns was the only one that had ever pierced a wrought-iron plate 4 inches thick; but even if such were the case he would not be justified in the inference he had drawn, in the absence of experiments with rival guns of equal weight and bore.

Sir W. Armstrong trusted he had said enough to explain the views by which he had been guided, in the construction of his rifled ordnance, and to show how fallacious it was, to judge of a cannon, without reference to the destructive character of the projectile it was adapted to throw. He did all honour to Mr. Whitworth, for the energy, perseverance, and skill, which he had displayed in this matter, but he denied that his results had proved the superiority of his system. There was, in fact, much less difference between the two systems than was commonly supposed. Both Mr. Whitworth and Sir W. Armstrong adopted loading at the breech, and both used a fitting shot. Mr. Whitworth closed the breech of his gun by an external screw, while Sir W. Armstrong used an internal screw for the same purpose. The former swung back the entire breech on a hinge, while the latter withdrew a stopper. Then as regarded construction, Sir W. Armstrong's original gun, made more than five years ago, and which was still in existence, consisted of an internal tube of steel, jacketed with wrought-iron coils. Mr. Whitworth's 80-pounder gun, now brought forward, was understood to consist of a tube of homogeneous iron, (differing from steel more in name than in reality,) jacketed in the same manner with wrought-iron coils. Mr. Whitworth would correct this statement if it was erroneous. The greatest difference between the two guns was in the rifling; but whatever might be the practical considerations affecting the two methods, theoretically speaking, so long as the requisite rotation was given to preserve the stability of the projectile, it was a matter of indifference what form of rifling was employed. Sir W. Armstrong conceded nothing to Mr. Whitworth even in regard to range. If the question at issue was one of range, let it be so understood, and let each party make a gun and projectile for the attainment of that object; but the real question was, or ought to be, which system would inflict the greatest amount of injury upon an enemy, and upon this ground Sir W. Armstrong was ready to meet Mr. Whitworth in friendly contest. If it should be replied, that Mr. Whitworth did not contend with Sir W. Armstrong in regard to projectiles and fuzes, then he would say, Mr. Whitworth was at liberty to adapt to his guns, if he pleased, the shells and fuzes then exhibited. When that had been done, let them meet at Shoeburyness, and fight the

matter out in a quiet business-like way. The targets there would represent enemies, both at long and short distances, and they could have earthworks, and masonry, iron plates, and timber-framing, to operate against. It would then be seen which system was best adapted for the defence of the country; and whatever the public might be induced to believe, Sir W. Armstrong trusted that, in the mean time, the Institution of Civil Engineers would withhold its judgment, until such a trial had been made.

In answer to questions from various Members, put through the President:—

Sir W. Armstrong stated, that the weight of the 12-pounder gun was 8 cwt., and the pitch of the rifling was one turn in thirty-eight diameters. The ordinary charge of powder was one-eighth the weight of the projectile, or $1\frac{1}{2}$ lb. of powder for the projectile now used in that gun. The chamber was made a little larger than was sufficient for that charge; in fact, it was of a capacity to admit of the largest charge, compatible with the permissible recoil of the gun. No inconvenience had been experienced from having a little vacancy in the powder chamber.

The index of the short-range sight was graduated for distances of 50 yards, by actual trials of the range at two, or three points, and interpolating the other divisions.

The initial velocity of the shot was about 1,100 feet per second.

The weight of the 100-pounder gun would be about 70 cwt.

The outer layers and rings of metal were not put on with any calculated degree of tension; they were simply applied with a sufficient difference of diameter to secure effective shrinkage.

The grounds for concluding that the range, through a resisting atmosphere, was greater than 'in vacuo,' were, that at a low elevation the actual range exceeded the parabolic range.

The ship guns, now in progress of construction, were on the same principle as the 12-pounder exhibited.

The longest range, hitherto obtained, was upwards of 9,000 yards, with a 32-lbs shot and a charge of nearly 6 lbs. of powder, from a gun, 4 inches in bore. In cases of extreme range, the state of the wind was an important consideration. The time of flight of that shot was not ascertained, as the graze was too distant from the gun to be seen. That distance must not be looked upon as the maximum range attainable with guns of this construction.

The bore was not of uniform diameter throughout the gun. There was a slight contraction immediately in front of that part, where the shot was lodged, the object of which was to mould the lead covering into the grooves to a sufficient depth, at the first instant of motion, to give the shot freedom in passing through the remainder of the bore.

The lead covering had not been observed to be stripped from the shot, by using very heavy charges of powder.

With trained men the 12-pounder gun could be fired three times in ninety-five seconds, with such accuracy as to strike a target each time, at a distance of 1,200 yards. Without taking aim, the rapidity of firing would, of course, be considerably greater.

A pressure of several tons was required, to force the shot through the contracted part of the bore; but after it had passed that part it was free. It was a mistake to suppose, that any loss of velocity was occasioned by that resistance; because the more the shot was held back, the more the pressure accumulated behind it. To obtain the maximum effect from the charge, the shot would require to be held back, until the combustion of the powder was perfected. The resistance had been varied, by increasing and diminishing the thickness of the lead coating upon the projectile, and it was found that the range was rather increased by augmenting the resistance. No difference in the recoil could result from the increased resistance. The recoil was due, simply and solely, to the weight and velocity of the shot from the gun. Nothing affecting the shot, whilst in the bore, could increase the recoil, unless it augmented the velocity. It was merely a question of action and reaction; and the quantity of momentum, generated in the shot, must have its exact equivalent in the recoil of the gun.

As far as experience at present demonstrated, a length equal to about twenty-five diameters of the bore, appeared to be the best proportion; that length might, under certain circumstances, be somewhat reduced, without much sacrifice of velocity. Whether that rule held good for all diameters, remained yet to be proved.

No inconvenience had, hitherto, been observed from heating. About a year ago, when the wet sponge was used, one hundred rounds were fired in succession from an 18-pounder gun; beginning at the rate of one round in two minutes, and gradually accelerating to one round in forty seconds. At the end of the experiment the gun was not objectionably heated. There would not appear to be any reasons for a difference in the heating of these guns, and of those of ordinary construction. The smaller charges would compensate for the diminished quantity of material in the gun.

In a recent trial, at Shoeburyness, a plate of wrought iron $4\frac{1}{2}$ inches thick, 6 feet long and 3 feet wide, had been entirely broken up and destroyed, by eight shots of 80 lbs. weight, fired from one of Sir W. Armstrong's guns, having a bore, 6 inches in diameter; the weight of that gun was 63 cwt., and the charge of powder was 10 lbs. Six of these projectiles were of cast iron, and the other two were of puddled steel. Only two of them actually pierced the plate, and none of them penetrated both the plate and the timber back-

ing. On a former occasion, on firing against wrought-iron plates 4 inches thick, upon a floating battery, two of the shot traversed both the plate and the timber, in addition to which, one of them cut through some strong ironwork within the ship, and drove two pieces of the iron plate across the deck, lodging them in the timber on the opposite side. That was done at a very short range, less than 400 yards, and with flat-ended shot, such as Mr. Whitworth had previously used. With rifled projectiles of heavy weight, the velocity was so well maintained, that there appeared to be no sensible difference in penetrating power, between 50 yards and 500 yards. Still Sir W. Armstrong would admit, that up to the present time, no gun of his construction satisfied the conditions requisite for thoroughly and completely punching through thick wrought-iron plates. There was, however, no doubt that it could be done with a special gun. It was only a question of bore, and of a hard material, such as steel, or homogeneous iron for the shot. But the expense of such materials would almost prohibit their ordinary use.

Sir W. Armstrong concluded by describing the principle of the Nyctoscope, an ingenious instrument designed by him for enabling the gunners to maintain a fire upon any given object after nightfall. The principle of the instrument was to render a false object in the rear, or at one side, visible upon a vertical line in a mirror, when the gun was laid upon the true object. A lamp attached at night to the false object, became visible upon the same mark in the mirror, when the gun was in line with the true object. The vertical adjustment for elevation was effected by a spirit-level clinometer, forming part of the instrument.

Captain Noble, R.A., corroborated the statements of Sir W. Armstrong. The computed initial velocity of the projectile was 1,080 feet per second, with a charge of powder one-eighth of the weight of the shot. With a 32-lbs. shot and a charge of powder of $5\frac{3}{4}$ lbs., at an elevation of 35°, the range from a gun with a bore of 4 inches, was 9,175 yards.

Mr. Bidder,—President,—suggested experiments for accurately ascertaining the velocity of flight of the shot; the electric telegraph afforded means for making them.

Mr. J. Locke, M.P., (Past-President,) thought the Meeting would lose a great advantage, if they did not ask Mr. Whitworth to repeat some of the explanations as to the experiments he had made, in order to contrast the results with those which had just been stated by Sir William Armstrong. Mr. Whitworth had given a very interesting account of his experiments; but there were still others of not inferior interest which had not been given, and he thought the present would be a fitting opportunity for hearing them. There were many apparent points of difference between the two guns,

which required explanation. Those differences seemed to consist, chiefly, in the mode of constructing the guns, in the system of rifling, in the form and dimensions of the chamber, as compared with those of the gun itself, and also in the different modes of closing the breech. All these were matters of importance and value, and being himself a non-professional man, in the art of war, he should like to hear those matters explained by the two gentlemen who had invented the systems. There was supposed to be a certain amount of friction in the passage of a projectile sheathed with a leaden coating, through the rifle grooves; and these latter were also understood to be liable to be, if not stopped up, at least, to become foul. All these points had occupied attention. Mr. Whitworth had stated, that there was no fouling in his gun, because with two metal surfaces working against each other, and a lubricating wad, no such effect could be produced. These were extremely interesting questions, and he thought this was a suitable occasion for Mr. Whitworth to give some explanation of the points to which he had alluded.

Mr. WHITWORTH said, he was ready to answer any questions that might be put to him, but as he had already explained the principle of his gun, he submitted that it would scarcely be in good taste to interfere with the explanations which had been given by Sir W. Armstrong, or to interrupt the lucid replies which he had made to the questions that had been asked. Still if it was desired, he would extend his remarks, describing his own gun, and pointing out the difference between it and Sir W. Armstrong's gun. With reference to a trial of their respective guns at Shoeburyness, he should be most happy to meet Sir W. Armstrong there, and should only stipulate, that some members of the Civil Engineering profession should be present at the trial, which he hoped would result, in securing for the country the best and most effective gun that could be manufactured.

Colonel EARDLEY WILMOT, R.A., said, he might perhaps be allowed, as an Artillery Officer, to express his acknowledgments to Sir W. Armstrong, for the able and lucid explanations just given of the new breech-loading gun. He was sure his brother officers could not be otherwise than highly gratified with those explanations. Upon one point especially, Sir W. Armstrong had done good service, by urging so strongly, that, provided a good form of rifled projectile was used, the particular form of the grooves in the gun was immaterial, as regarded any marked difference in the accuracy of the weapons, with shot of the same material. It appeared now, that the great points to be attended to were, simplicity of manufacture and cheapness; because the day would come, when cost would form a more important element than it appeared to do at present.

Sir William Armstrong mentioned, that the cost of the 12-pounder gun now exhibited, complete in all respects, was less than that of the old 9-pounder brass gun.

Colonel Wilmot explained, that whilst the cost of labour upon a 9-pounder, or 12-pounder brass gun was almost nominal, it must be remembered that, after it was unserviceable, or obsolete, it was almost as valuable to sell, as old metal, as it was before.

Sir William Armstrong trusted that his guns would be almost everlasting.

Colonel Tulloh, R.A., called attention to the important advantage possessed by the Armstrong gun, in having a muzzle of so small a diameter, as to allow of the port holes of vessels being much reduced in size, probably to one-half what they were at present.

Mr. Whitworth, in compliance with the request of the President and many of the Members, exhibited one of his 12-pounder breech-loading guns, and specimens of the different projectiles, solid and hollow, which he used with his rifled guns of different calibres. He observed, in reference to his system of projectiles, that it had been said, he obtained long range by excessively reducing the diameter of the shot. To show that this was incorrect, he exhibited one of his 12-pounder shot which had been fired. The minor diameter of this shot, measured across the flats, was $\frac{1}{10}$th less than 3 inches, while its major diameter, measured across the angles, was $\frac{2}{10}$ths greater than 3 inches. This was larger than Sir William Armstrong's 12-pounder shot, the diameter of which was only 3 inches. It was, therefore, incorrect to state that he sacrificed capacity to obtain range, and that his gun was more suited for shot, than for shell. The contrary of this was the case. His 12-pounder shell was 12 inches long, and the diameter, as before stated, was $3\frac{2}{10}$ths inches. Now it was obvious, comparing the solid and the hollow projectiles, that the increased length of the hollow projectile must add to its capacity and effectiveness. The shell might be built up inside, on the segmental plan, or shrapnel might be used; but he should prefer a simple hollow shell, such as he exhibited, as the minor diameter being slightly smaller than the major, it would, necessarily, split up along the centre of the flats, as they were the weakest parts. When the shell was fired, it was broken into the desired number of fragments, according to the grooves inside, and the size of the fragments might be regulated, so as to make them very effective projectiles. The number of fragments into which a shell was broken up, was not a correct test of its destructive power, as very many of the pieces might be too small to be effective. With regard to the ignition of this shell, the percussion system and a moveable striker could be employed, on the plan described in the specification of Mr. Tucker, in 1829, afterwards adopted by

Mr. Lancaster, and subsequently patented, with improvements, by Sir W. Armstrong. Mr. Whitworth could use the more simple and certain time fuze, which was placed in front of the shell, and was ignited by the flame of the powder charge. By removing a portion of the outside of the shell on two opposite edges, the flame passed by the projectile, and readily ignited the time fuze in front. This shell was, therefore, very simple, and its cost did not much exceed that of the solid shot.

Before proceeding with further remarks, induced by the President's request that he should exhibit one of his large guns, Mr. Whitworth requested the Members to excuse any repetition of the observations he had previously made.

Mr. Whitworth then explained, that he had used a tubular shot for penetrating wood and elastic materials, by which a core, or cylinder of wood, nearly 2 feet long, and 1½ inch in diameter, had been cut out of a solid oak block, through which the tubular projectile was fired. The tubular was also the best form for penetrating masonry. The flat-fronted shot, which he showed, was like those that were fired through 30 feet of water and 8 inches of oak, at Portsmouth, from a brass howitzer rifled by him in 1856. He employed the same form, with malleable, or homogeneous iron shot, for piercing thick iron plates. He might mention, that having been the first to use the flat-fronted shot, he, for self-protection, included it under a patent, but had placed it, with other improvements, at the disposal of the Government. Sir W. Armstrong had told the Meeting that he had now adopted this form of shot, for a similar purpose.

Another form of shot was the spherical, rifled hexagonally. It was thought, that spherical shot would be best for ricochet; but Mr. Whitworth's experiments showed, that the improved elongated form of shot, he now used, was superior in that respect. These different projectiles, both of shot and shell, though of various lengths, could all be fired from the same gun, as occasion required.

Mr. Whitworth then described some projectiles, which were merely intended as experimental shot. The first was a shell, ten diameters in length, which was fired from a 24-pounder howitzer, rifled by him in 1856. The diameter of the howitzer was 4 inches, and the twist was one turn in 40 inches. The spherical shot and this experimental shell, were instances of two extremes, with regard to length; the one being one calibre, the other ten calibres long. Both could be fired from the same gun, as it had no chamber. The best practical length of shot was between the two extremes. By actual trial of various proportions, he had ascertained which length gave the greatest momentum, and that he adopted, not because it gave the greatest range, but because it produced the best general effect.

The metallic cartridge, which he showed, was made of tin plate, and had a rifled shape to fit the bore. When it was inserted in the gun, it formed a lining within which the charge was fired. The powder, therefore, instead of acting against the sides of the gun, acted against the inside of the cartridge. This saved the gun; and moreover, when the cartridge was withdrawn after the discharge, it brought away with it the fouling deposit. A small hole was made in the rear of the cartridge case, through which the fire from the friction fuze was flashed to the powder. The case was filled with powder to within about $\frac{1}{2}$ an inch of the open end. It was then closed by a wad, of lubricating material, which, when the charge was fired, was distributed over the interior of the gun. This obviated the necessity of sponging out, which had always been a great inconvenience in working guns. He believed this plan of obviating the necessity of sponging, by the use of the wad of lubricating material, had not been used, previously to his adopting it.

Mr. Whitworth proceeded to show the mode of working the gun. The gun was loaded by unscrewing the breech cap, and inserting first the shot, and then the metallic cartridge, containing the powder and lubricating wad. The breech cap was then screwed on the gun, by a few turns of a handle. Supposing the gun to have been discharged, the cartridge case was withdrawn, by a small and ingenious instrument, bringing with it the fouling residuum. Besides the convenience and cleanliness of this plan, it, as before stated, preserved the gun from the action of the powder. Those who had witnessed the operation of loading could form their own opinion, as to the conditions under which a simple, hard metal shot was propelled through the six-sided bore, when well lubricated, and could compare them with those, under which a lead-coated projectile was driven through the fluted bore, and had to cut its way through the thirty-four grooves. It had been stated, that there was not much difference between the Whitworth hexagonal gun and the Armstrong fluted gun. In that statement Mr. Whitworth did not agree; and in order to enable the Members to judge for themselves, he would point out some of the differences between the two systems. As to material. The hexagonal gun was made out of a single ingot of homogeneous iron, forged under the ordinary tilt hammer. This material partook of the toughness of copper and the hardness of steel. The Armstrong fluted gun was a compound piece of forging, made by welding up separate bars of iron, requiring special furnaces of very great length, and special forging machinery. The iron was fibrous, and comparatively soft, and could not be expected to last as long as the tougher and harder homogeneous iron. Of the admirable workmanship of the Armstrong gun, which had been made at Woolwich, there could be but one opinion; and the greatest

credit was due to Mr. Anderson, for the skill with which he had, in so short a time, organised an establishment capable of turning out such work. In weight, the guns were equal. In bore, the major diameter of the hexagonal gun was $3\frac{2}{10}$ inches, that of the fluted gun was $3\frac{1}{10}$ inches, the rifle twist being one in 60 inches in the former, and one in 114 inches in the latter. Consequently, twice as much rotation was given to the Whitworth projectile, which the results of repeated experiments had shown to be highly desirable. As to form of bore, the Whitworth was a six-sided spiral, while the Armstrong was a spiral with thirty-four fluted grooves. The hexagonal gun was rifled uniformly throughout its entire length, and required no chamber. The fluted bore was not rifled uniformly, having a contracted part near the chamber; and the chamber itself being of a fixed length, limited the length of the projectile and the charge of powder that could be used. In the Whitworth gun, the breech was closed by a cap, working in a hinged hoop, and fitting on the end of the gun, with an external screw. In the Armstrong gun, a slotted recess received the moveable breech-piece, and behind that, a considerable length of the gun was taken up by an internal screw.

As to the projectiles, the Whitworth hexagonal gun fired both shot and shell, of various lengths and forms, to suit special purposes. The shells were of great capacity, and might be ignited, either by the simple time fuze, like the ordinary shell, or by employing the percussion system. From the Armstrong chambered fluted gun, shot, or shell, of a fixed length only, could be fired; and as the lead was forcibly driven through the grooves, there was no windage, and the flame could not pass by to the front. Hence the percussion system of strikers was required. It was a mistake to suppose, that any serious loss arose, from allowing a small amount of windage. Mr. Whitworth had fired, from the same gun, an iron shot, rifled on his plan, (in which a small amount of windage was purposely allowed,) and leaden shot of the same shape and size. The leaden shot was, necessarily, expanded by the explosion, until it filled the bore, and was propelled without there being any windage at all. But, although its specific gravity was greater than that of the iron shot, and it had no windage, its range was not nearly so good as that of the iron shot. Again, in the hexagonal gun, the resistance offered to the projectile at starting, was only that due to its 'vis inertiæ;' and the only retardation, being that caused by the rifling, imparted an increased efficiency to the projectile. In the fluted gun, it appeared, that a pressure of several tons was required to start the shot; it had, moreover, been said, that this did not cause any loss in range, it being, on the contrary, supposed to be advantageous, to retain the shot and to give the gases of explosion a longer time to act. If that were the case, it would seem preferable to

retard the shot, by giving it increased rotation, and therefore increased power, rather than to expend a pressure of several tons, in forcibly rifling the shot. This brought under consideration another important difference between the two systems. The mechanically fitting hexagonal projectile was rifled by machinery in the workshop; whereas the lead-coated projectile, used with the fluted gun, was rifled by the explosion in the gun itself. On the economy and advantage of the former plan, it was not necessary to dwell. In the hexagonal gun a metallic cartridge was employed, which, both in practical use, and for carriage and storage, had many advantages over the old flannel bag, which was still retained with the fluted gun.

As to practical results, Mr. Whitworth did not now propose to carry out the comparison. But something ought to be said as to range, which he was surprised to hear undervalued. Without attaching too great importance to mere range, it must be admitted to be a very good measure of what the gun could do. If at an elevation of 7°, the range of the fluted gun was 2,495 yards, and the range of the hexagonal gun was 3,107 yards, the trajectory of the latter was flatter, and the errors in judging distance were of less importance, as during a greater portion of its flight, the hexagonal projectile was nearer the ground. This perhaps would appear more plainly, by comparing the range of the fluted 12-pounder gun at 9°, which was stated, on good authority, to be 3,000 yards and upwards, with the range of the hexagonal 12-pounder at 7°, which was 3,100 yards and upwards; now considering the ranges as about equal at these different elevations, the advantage of firing the hexagonal gun at 7°, as compared with another gun, which, to attain a like range, required to be elevated to 9°, was obvious. The gun which had the longer range and the flatter trajectory was more likely to hit a distant object, than another gun which had one-fifth less range, for the same elevation.

In constructing the rifled cannon, Mr. Whitworth had only applied the same principles which were found to be successful in the rifled musket. The results of the late experiments at Southport, on the Lancashire coast, though many of them were made without any previous trial, were such as he was justified in expecting, knowing how certain and simple were the principles on which reliance was placed. In gunnery, as well as in other things, especially those depending on mechanical principles, to simplify was to improve. The special object he had in view, in carrying out the system he had endeavoured to explain, was to reduce the principles, on which it was based, to their simplest elements.

Mr. Whitworth stated, in reply to a question from the President, that the charge of powder for the 12-pounder gun was $1\frac{3}{4}$ lb.

Sir William Armstrong said, the comparison as to ranges, which had just been brought forward, was with $1\frac{3}{4}$ lb. of powder in

the Whitworth gun, against 1½ lb. in the Armstrong gun. As a general observation, he objected to comparisons of ranges and results, unless the experiments were made at the same time, under the same circumstances, and with the same object in view.

Mr. W. B. ADAMS,—through the Secretary,—said, the proposition of Mr. Longridge, to make a gun that could not be burst, was, evidently, the true basis on which to work, in the improvement of artillery. It must be clear, that all power generators, or receptacles, must be strong enough to hold and to maintain the power, while applying it. To make the strongest gun, required the strongest material, if it was practicable to use it, and drawn wire was the strongest at present known. Mr. Longridge had succeeded in making the lightest gun yet produced, of great transverse strength, by an endless skein of wire; and the problem of longitudinal strength by endless skeins of wire was, if needed, not difficult of solution. Nor need there be any fear of the wire becoming loose, for it might be of tempered steel, giving constant reaction against strain, and it might, moreover, be soft-soldered together to prevent it from unwinding. For the purpose of transport, it was evident, that lightness was a most important quality, but for use in the field another quality was required, weight to induce enough inertia, so that the whole of the force of the powder might be expended in moving the projectile, while the gun remained unmoved. And this weight was best applied over the whole surface of the gun, and not merely at the breech; otherwise, the jar on the light muzzle would disturb the accuracy of aim. For this reason it had been, that English duelling pistols, and American rifles, had usually been constructed with heavy and nearly parallel barrels. As regarded the question between built guns and solid forgings, the present practical condition of the art of forging made the former mode preferable; but it was probable, that ultimately, a mode of welding by jets of intense gas flame, instead of by furnace heat, would enable the manufacturer to pile any mass of iron together in perfect welds, without any oxidation of the surfaces internally, or, which amounted to the same thing, the malleable iron could be cast, by the Bessemer process, to any size, and subsequently hammered. Still, if a large gun, easily transportable by land, was required, it was a problem whether a gun of given lightness could be made stronger of wire, or of solid metal; and this was an important problem, for the projectiles of enormous bulk and weight, which would, henceforth, be required for siege purposes.

In the modern use of guns a circumstance had arisen, varying from the old practice. The powder was so highly explosive, that it became a violent sudden shock, instead of an expansive force, like steam in a cylinder. While loosely fitting round shot were used, the strain in the gun was relieved by windage. With

the modern elongated shot, expanding lead into rifle grooves, windage was prevented, and the strain was at its maximum. The powder of ancient times was slow burning, and gradually expansive, and for that reason the guns were made of great length, in order to expend the whole power on the shot, previous to its leaving the gun. The advantage said to be obtained, by what was called a 'gaining twist,' in rifle guns, afforded a strong inference, that sudden shocks were considered mischievous. It was, therefore, worth while to consider how powder might be used with an increasing pressure, without a sudden shock; possibly, by firing it from the front portion, next the projectile, as in the Prussian needle gun, instead of at the rear, as was usual with all cannon.

The next question was, as to the best mode of stopping windage. At present, the approved methods were by violently and explosively moulding a leaden plug into the bore of the barrel, or by fitting a long bolt by machine tools. Now a rigid fit was not used in a steam cylinder, which was analogous to a gun in its operation; elastic steam being used instead of elastic gas. The piston of a steam cylinder had an elastic packing, involving little friction, without suffering any steam to escape past it. An important element in the construction of an elongated shot was, to keep its longitudinal axis parallel to the bore of the barrel, and this was by no means certain with the leaden plug, which might yield more on one side than on the other, with the sudden explosion. A solid iron shot would not be subject to this difficulty, but the fit would vary and the windage would increase as the gun became heated.

In regard to the question of rifling the bores of guns, which seemed to be generally assumed as a principle not to be dispensed with, it was still doubtful whether further experiments would not dispose of it altogether. In truth, rifling was simply a contrivance for correcting the defects of badly constructed projectiles, at a considerable waste of propelling power. If the centre of gravity of a spherical shot was not in the exact centre, it would, when put in motion, move in a curved line, instead of a straight line. As it was a mere matter of chance, where the bias of a shot would be in the gun, it was uncertain where the projectile would fly to. The spinning motion given by the rifling, to some extent corrected this. But if the centre of gravity was exactly in the centre of the shot, there seemed to be no apparent reason, why it should not take the exact direction given by a true propelling cylinder. With elongated shot, as commonly made, not only might the centre of gravity be out of the line of the central axis, but almost invariably, when made with its sides parallel and with a conical point, it would, when placed in the gun, have the centre of gravity behind the middle of the length. Therefore, on leaving the gun. it would try to turn over, to get the heaviest end foremost, and to

prevent this, a large quantity of power was expended on rifle-spinning it.

But if the centre of gravity was far in advance of the middle of the length, there would not be any tendency to turn over, and if the centre of gravity was in the central axis of the gun, and the chase of the gun was long enough to determine the line of flight, there seemed no probable reason why the projectile should fly astray.

There was some analogy in the form of the arrow, or 'cloth-yard shaft,' used with the long bow. The diameter was to the length less than 1 to 72. The centre of gravity was, forwards, two-thirds of the length, and the steel head gave it a slight additional weight. The longitudinal axis was perfectly straight, and in the centre of the diameter all through, and two, or sometimes, three feathers at the hinder end, corrected all tendency to aberration in the flight. The muscular power with which it was propelled was from 50 lbs. to 60 lbs., and it was stated to have a range of 600 yards, which could be repeated twelve times in a minute. But all depended on the accuracy of construction. If the arrow was crooked, or the feathers were badly applied, the accuracy of flight and the length of range were impaired.

An arrow could not, for many obvious reasons, be fired from a gun. The problem therefore, was, how to make a metallic arrow which should carry its weight chiefly in the head, which should keep its longitudinal axis in the longitudinal axis of the gun, which should fit the bore elastically, with sufficient tightness to prevent all windage, without involving unnecessary friction, and with the propelling power applied near the head, drawing it, as it were, along the chase of the gun, instead of propelling it from behind. When this should be accomplished, and it did not seem a very difficult problem, the length of the gun should be so proportioned, as to consume the whole elastic power in propelling the shot, and not wasting it externally, as in carronades. And the longer the gun, the truer would be the aim and direction.

The advantages of getting rid of the rifling process would be, a gun more easily made, more easily kept in order, and considerably stronger, with a given weight of metal. But it was also important, that the shot should be in a convenient shape for stowage and transport, and moreover, be cheaply and readily produced.

It was not necessary to allude, particularly, to the construction of the Armstrong and the Whitworth guns. Both, if exceeding 3 inches in bore, were of wrought metal, formed by shrinking reinforce rings, or tubes on to a central tube. Both were breech loaders; both were rifled; both carried elongated shot; both were provided with a lubricator in front of the powder; both had their vent on a moveable part, capable of replacement when worn; and both were combinations of parts.

Now, as to the respective merits of the two systems. It was claimed for the Whitworth gun, that it was both a breech and a muzzle-loader, with its one prepared shot, whilst the Armstrong gun was only a breech-loader. This was not important, as muzzle-loading would only be resorted to, in case of something going wrong with the breech, which would, probably, render the gun useless. But the Armstrong shot could very easily be converted to muzzle-loading, by driving it through an iron collar, to strip off the lead covering. As regarded the rifling, a certain amount of surface was essential, to prevent the lead from slipping its threads by the twisting action. With few grooves they would require great depth, whilst by multiplying them, a less depth sufficed, and there was less risk of bursting. With the flat grooves of Whitworth, there was a tendency to draw them into a true circle, when the powder exploded. Theoretically, the outside of the gun should correspond to the inside in the number of the flats.

With respect to projectiles, Mr. Whitworth had the advantage in a hard material, which might be thrown down like ordinary shot without much damage, unless when exposed to rust, which, however, might be provided against by galvanising. The lead-covered Armstrong shot required to be treated carefully, and each would have to be packed in a separate box, to save the lead from damage. The Whitworth elongated shot, tapered at both ends, was much more in conformity with the established rules for passing through fluids with the least resistance, than were the parallel shots with conical heads. The statement of Sir William Armstrong, that the shot always advanced along the trajectory curve parallel to the axis of the gun, with its tail hanging down, simply proved, that it was not in balance, and that the heaviest end hung down in the tendency to get forwards, which was impeded by the spinning movement. An arrow in balance always fled parallel to the trajectory curve.

Mr. Whitworth, in his specification, claimed the original arrangement of a tallow box in front of the powder. Sir William Armstrong, after experience of the disadvantages of washing out the gun, enclosed the tallow in a ball of hemp.

It could not be denied, that with great outlay and a series of long-conducted careful experiments, both these gentlemen had accomplished an amount of precision and length of range never before known with cannon. But the principle of the whole was to be found in the elongated shot, the absence of windage, and the greased projectile, a combination common to all well-made and well-used shoulder rifles; and they had produced gigantic rifles, as perfect in all their arrangements as the best-made philosophical instruments.

Other things being equal, there could be no doubt, that length of range was an important advantage; but for practical fighting, in

the field, on ship board, and in forts, simplicity in the fighting machinery was very important. Breech-loading was important for many reasons, and both Whitworth and Armstrong had done good service, in showing that efficient breech-loading cannon could be made. But there did not appear to be any absolute reason why these breech-loaders should not be simplified. If the chamber where the powder was placed was reinforced externally, to a sufficient size, it might be pierced, at the back of the powder, transversely to the bore, with a slightly conical hole, larger than the bore, and this hole being stopped with a pin, with a slot in the small end with a key to tighten it, and a slot in the large end to loosen it, a perfectly practicable breech-loader would be obtained, without needing any screw whatever, the whole workmanship being of the simplest kind, and suited to the habits of working artillery-men. Screws of accurate workmanship constantly moved, and being liable to the sprinkling of sand, or gravel, would be easily rendered useless. The vent might be made through the coned pin, but it would be better to make it through the gun, near the front of the powder, so as to burn it backwards. Much stress had been laid on the importance of preventing the escape of gas, at the back of the breech. Sir William Armstrong applied a copper cone for this purpose, and Mr. Whitworth was very careful in the fit of the screw cap. But the effectual stoppage of gas, or windage, behind the powder, could not be more difficult than in front of the powder. If a wad of lead, or of papier mâché, were applied behind the powder, it would have precisely the same effect as behind the shot, and with a breech-loader might be more easily moved, after discharge, than the ordinary wad in a muzzle-loader.

No comparative experiments had yet been made, between the results of one of these new rifled cannon, with all its appliances, and elongated shot, and the best possible construction of a smooth-bored cannon, and appropriate shot; considering the range, force, accuracy, and cost. With the rifled cannon, it was said, that the armour plates, 4½ inches thick, of a vessel had been pierced. There was little doubt, that a smooth bore driving the projectile with equal force, would better punch a hole, by reason of the absence of the spinning movement. If a revolving punch was applied to an ordinary punching machine, it was more than probable, that the punch would be broken.

In naval warfare there were, up to the present time, two modes of fighting; 'long-bowls,' and 'yard-arm and yard-arm.' For the latter purpose, breech-loading guns of great weight, ending at the muzzle in a large ball fitted to a close socket in the ship's side, with a wheel behind, on which to traverse about and depress, would be a good arrangement, leaving no opening, except at the front sight of the gun. There would be no smoke aboard, and by means

of water hose, the guns could be rapidly cooled down when required. Means being taken to prevent the recoil, two men could work a gun as easily as a dozen, without being exposed to shot from the enemy.

For 'long-bowls,' heavy non-recoiling artillery, probably mounted with a central ball, in a socket, instead of trunnions, and capable of moving vertically and horizontally, would best serve; and when that was accomplished with a gun of ordinary calibre, attention might be given to the idea of Mr. Mallet, of throwing into fortresses shells large enough to be termed 'portable mines;' only, in order to get the best result, cylinders must be used instead of spheres, for projectiles.

Objections had been taken to the great cost of the Whitworth and the Armstrong guns. If this cost were essential to great and undoubted superiority, the English nation ought to rejoice at it, as giving at once the advantage to their long purse. But if an equal effect, or a greater effect, could be produced by simpler means, then it would be a sorrowful disadvantage to the English nation to make expensive guns, while their foes were making cheaper ones.

Upon the whole, the improvement in artillery was favourable to the cause of humanity, for fortresses, the strongholds of irresponsible power, would be no longer defensible. Long-range guns of enormous power of propulsion would explode them, and their only defences would be mounds of earth, easy for numerous assailants to swarm over. The cost of armies must be enormously augmented, by increased numbers, when they could no longer be sheltered by fortresses, and their expense would, ultimately, be destructive to the nation depending on them.

Meanwhile, the threshold of improvements in artillery was only now reached, and the subject had yet to be exhausted, before it would be safe to rest upon the present amount of knowledge.

Mr. LONGRIDGE said, before replying to the remarks which had been made, in the course of the discussion, he might be allowed to refer, for a moment, to a matter personal to himself. He was sorry that anything in his Paper should have been construed into an attack, either upon military authorities, or upon the Select Committee on Ordnance, at Woolwich. From some of the observations, it appeared as though he had drawn up the Paper with the express purpose of decrying military men and exalting his own profession, or of venting on the Select Committee the spleen of a disappointed inventor. If that had been his intention, he would have been unworthy to be a Member of this Institution; and he was sure that had the Paper been justly liable to this reproof, the Council would never have allowed it to be read. But in point of fact, not a word in his Paper could be fairly construed in that sense. What he said was this; that the Civil Engineer,

from his daily practice, was more conversant with the properties of the useful metals, than his military brethren; and might, therefore, be allowed, without presumption, to discuss the question how to make a strong gun. He still adhered to that opinion. With regard to the Select Committee, he had the highest respect for certain members of that body; and amongst them, for the gentlemen who had taken part in this discussion. It had been remarked, that it was not right to attack an absent body. Even if that had been done, the Committee had ample opportunities of defending itself, through such of its members as were invited to be present. It had, moreover, been said, that whether the matter, brought by Mr. Longridge before the Committee, had been fairly dealt with, or had received due consideration, was open to fair argument. He thought he could show, by a few observations, that it had neither been fairly dealt with, nor fully considered. When he said this, he did not intend to convey any charge of personal unfairness; but he contended, that the project did not meet with that consideration, to which it was entitled from the experiments and results, laid before the Committee. He thought too that, personally, he had not been quite fairly dealt with, by members of that Committee who had taken part in the discussion. It had been represented, as though he had sent a gun to be reported upon by the Committee. He did no such thing. All that he placed before them was a simple brass cylinder bound round with wire. In introducing it to their notice, he took care to state, that it was not a gun, but merely an illustration of what he conceived to be a means of obtaining great circumferential strength in a gun. He also handed in a written description of how guns might be made upon that principle, and also how the trunnions were to be attached. That written description was accompanied by two drawings,—one of a 32-pounder and the other of a 10-inch howitzer,—showing how the trunnions were to be attached. He thought, then, that after explaining precisely what the construction of the cylinder was, (Fig. 12, page 308,) it could not be said, that his plan had been fairly dealt with, when this wire-bound brass tube was virtually hung by the muzzle and fired with 2 lbs. of powder; the usual proof charge for a 3-pounder gun being $1\frac{1}{4}$ lb. Under such circumstances, it could not be a matter of surprise to any one, that the breech should have been blown off. He believed, that a trial with the heaviest gun in the service, under similar conditions, would have been attended with the same results. Therefore, he submitted, he had made out a case, that the invention in question had neither been fairly tried, nor fully considered. In further proof of this, he might state, that he held in his hand a letter from a very influential member of the Select Committee, and one who had taken part in this discussion, written in September, 1855. He said:—"I believe it is generally thought, that the experiments

made, do not go towards any disproval of the leading idea of your proposition."

Before entering upon the subject of the Paper, he begged to be allowed to make a few remarks, upon one, or two matters which, incidentally, had come before them. He had been greatly disappointed that, in the course of the discussion, particularly, considering the presence of so many gentlemen of eminence, in this department of science, they had heard so little upon the subject of the effect of twist in rifled guns. Several descriptions of guns had been brought forward, varying greatly in the character of the twist, and for each class, superiority was claimed. But no clear explanation had been given of the effect of the twist, or indeed, what it was sought to effect. A note on this subject was appended to the Paper,[1] and he would now only briefly refer to such of the causes of deviation, as were affected by the rifling of the gun and shot. He believed a misconception existed upon that point, and therefore, he was glad of an opportunity of saying a few words upon it. The first object, in rifling a gun, was to correct the deviation, which was due to the want of symmetry in a projectile. When a projectile was thrown from a gun, if the resultant of the resistance of the air acted through the centre of gravity, there would be no such deviation; but inasmuch as an exactly symmetrical shot could not be practically obtained, when the shot met the resistance of the air, it was deflected to one side, or the other. To correct that deviation was the primary object of rifling; and it was supposed, that by causing the rotation of the shot, it would describe a series of spirals round the prolonged axis of the gun. That he believed was incorrect. The projectile did not describe spirals, but a series of curves, the general direction of which was a straight line, deviating uniformly from the prolonged axis of the gun, and the projections of which, on a plane at right angles to the axis, were of a cycloidal form. It was a mistake to suppose, that the shot described spirals round the prolonged axis of the gun. It made a deviation to one side, or the other, dependent upon the first impulse of the air, as the shot passed from the gun. A small amount of twist was sufficient to counteract that deviation. Taking, for instance, the three guns which had been more prominently brought before their notice: viz., Mr. Haddan's gun, with a twist of one turn in 40 feet; Sir William Armstrong's gun, with a twist of one turn in 9 or 10 feet; and Mr. Whitworth's gun, with a twist of one turn in 5 feet. In a distance of 1,000 yards, Mr. Haddan's shot would make sixty turns, Sir William Armstrong's, three hundred turns, and Mr. Whitworth's, six hundred turns.

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[1] *Vide* Appendix, page 325, *ante*.

The cycloidal curves, he spoke of, were very minute indeed, varying from $\frac{1}{30}$th to $\frac{1}{3000}$th part of an inch. The shot made a deviation equal to the length of the base of one of these curves, in each revolution. In a range of 1,000 yards, the deviation, in the case of Mr. Haddan's gun, would, therefore, be 2 inches; in Sir W. Armstrong's, $\frac{4}{10}$ths of an inch; and in Mr. Whitworth's, $\frac{2}{10}$ths of an inch. Consequently, a very small amount of twist was sufficient to correct the deviation, arising from the cause now under consideration. The next cause of deviation was due to the position of the centre of gravity of the projectile, and was well exemplified in the gyroscope. If the centre of gravity was behind the centre of resistance, the shot would deviate in a long spiral to the right hand, in a right-handed twist, and to the left, in a left-handed twist. If the centre of gravity was in front, the reverse would be the case; and the greater the velocity of rotation, the less would be the amount of deviation. To get rid of this deviation, great velocity of twist was required. This deviation was always due to the position of the centre of gravity. By arranging the centre of gravity as nearly as possible in the centre of the figure, this deviation would be, to a great extent, avoided.

There was another cause which, no doubt, operated in a considerable degree; the rolling motion of the shot upon the air. If a cylinder was rolled between two surfaces with different pressures, it would move itself in the direction of rotation, along the plane where the pressure was the greatest. The motion of a shot revolving and falling in the air, was of that character. The resistance on the top was less than on the bottom, and the rolling motion tended to move the shot to the right hand, if the gun had a right-hand twist. This deviation was greater, as the twist was greater; consequently, if he was correct in this position, it would appear, that the great amount of twist given to some of these guns, if really necessary, was only rendered so by the position of the centre of gravity in the shot. He could see nothing wrong in the reasoning which had led him to the principles he had laid down. This reasoning was fully given in the note before referred to.

There was another deviation, which was not confined to rifled guns, but was common to all ordnance; that was, the want of some means of adjusting the trunnions perfectly horizontal. In a long range, with high elevation, it was a very material point. If the trunnions deviated only 1° from the horizontal line, the elevation being 35°, a range of 8,800 yards gave a lateral deviation of 110 yards, and with an elevation of 10° and a range of 4,000 yards, the deviation would be 12 yards. Consequently, an error of 1°, which was so slight as not to be detected by the eye, gave

rise to important deviations in firing. He thought, that in any comparative experiments with guns, that point should be carefully attended to.

It was not difficult to calculate the amount of force required to give the twist. It was inconsiderable, even in the case of the Whitworth gun. He could not, however, agree with the statement made by Mr. Whitworth, that the amount of rotation helped the shot forward. He thought it had a contrary effect, and that whatever force was employed in giving rotation, diminished, to that extent, the longitudinal force; but the amount was inconsiderable. In the Whitworth 80-pounder gun, supposing the velocity of the shot to be 1,300 feet per second, the mean force, or pressure for that velocity, would be 306,900 lbs. throughout the length of the gun; whilst the force to give rotation, including friction, would be only 7,000 lbs.

The next point, upon which he would offer some remarks, was as to the force of gunpowder. He had estimated it at from 17 tons to 20 tons to the square inch. That result was arrived at from his own experiments. The plan adopted was, in his opinion, a correct mode of ascertaining the strength of gunpowder. The more ordinary way of estimating it was by two methods; first, by ascertaining the actual volume of the gases, and their expansion by the heat generated; and secondly, by experiments with the balistic pendulum. As to the first of these methods, the absolute knowledge was very imperfect. The volume of gases generated was known with tolerable accuracy; but not the actual temperature. The amount, however, of the heat given out by the carbon and sulphur of the powder was known, and the specific heat of the gases at a constant pressure; but what was required, was the specific heat at a constant volume, which though known for air, nitrogen, and sulphuret of potassium, was, he believed, not known accurately for carbonic acid. From these data, an estimate might be formed, which would bring the temperature to about 9,440°; and this would result in a pressure of about 42 tons per square inch, if the pressure was measured by Mariotte's law. As far as the experiments with the balistic pendulum went, Hutton had arrived at the conclusion, that the force of gunpowder was from 12 tons to 16 tons to the square inch. Captain Boxer, in his "Treatise on Artillery,"[1] calculating by the volume and assumed temperature of the gases, gave the force as 2,154 atmospheres, or 14½ tons to the inch. This, however, was on the supposition of the truth of Mariotte's law, as applied to the circumstances of the gases from gunpowder, a hypothesis which Captain Boxer correctly stated, the present state of knowledge would lead to doubt. Applying Hutton's formula to the Whitworth 80-pounder gun, and taking

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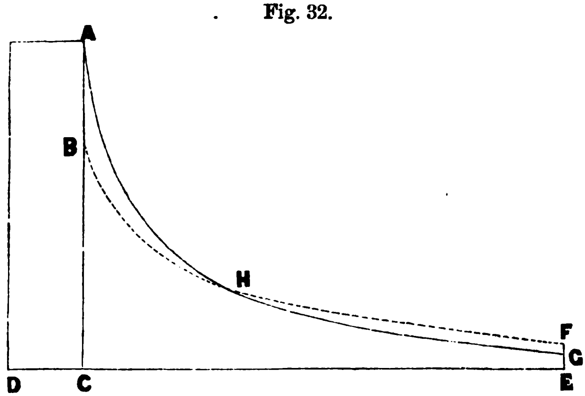
[1] *Vide* "Treatise on Artillery, &c.," by Capt. E. M. Boxer, R.A. Sect. 1, Part I. 8vo. London, 1854.

the velocity at 1,300 feet per second, Mr. Longridge found the initial force to be about 17½ tons per square inch, if Mariotte's law was used. But if, instead of this, the true thermo-dynamic law was made use of, the initial force would be found to be 24½ tons per square inch. In both cases, it was supposed, that the whole of the powder was burnt instantaneously. If, for example, D E, (Fig. 32), represented the chase of a gun, and D C the space occu-

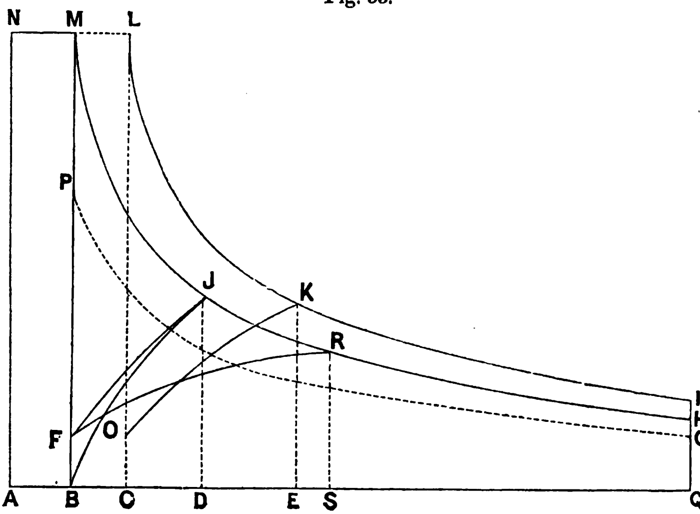
Fig. 32.



pied by the powder, then, if the explosion took place instantaneously, the pressures at any point would be represented by the ordinates to the curve B H F, if Mariotte's law was used; but by those of the curve A H G, if the true thermo-dynamic law was employed in the calculation. The curve A H G was what was called an adiabatic curve, or curve of no transmission; the amount of heat contained in the gases, during the whole process of expansion, being considered constant, whereas, according to Mariotte's law, the temperature was considered constant. It was, however, well known, that powder did not burn instantaneously; and it was important to know what effect the rate of burning had upon the initial force. With the view of illustrating this, he had prepared a diagram, (Fig. 33, page 439,) which he would explain. Taking A Q to represent the chase of the gun, and A B the space occupied by the charge, and applying Hutton's formula, modified by the adoption of the thermo-dynamic law, a curve P G would be found, whose ordinates would represent the pressures, and whose area B P G Q B, the work done. This was on the hypothesis of instantaneous burning. If, however, the powder did not burn instantaneously, the case would be different. As soon as the pressure behind the ball exceeded the friction, the ball would begin to move, and the space for the gases would increase. If F B represented the pressure needful to overcome friction, the curve of pressure would be somewhat like F J; the ordinates increasing up to a certain point, probably till all the powder was burnt. At any rate, let the ball be at D, when all

the powder was burnt; then D J would represent the pressure. From this point, the curve of pressure would be an adiabatic curve J H. Now the work done on the ball must be the same as in the

Fig. 33.



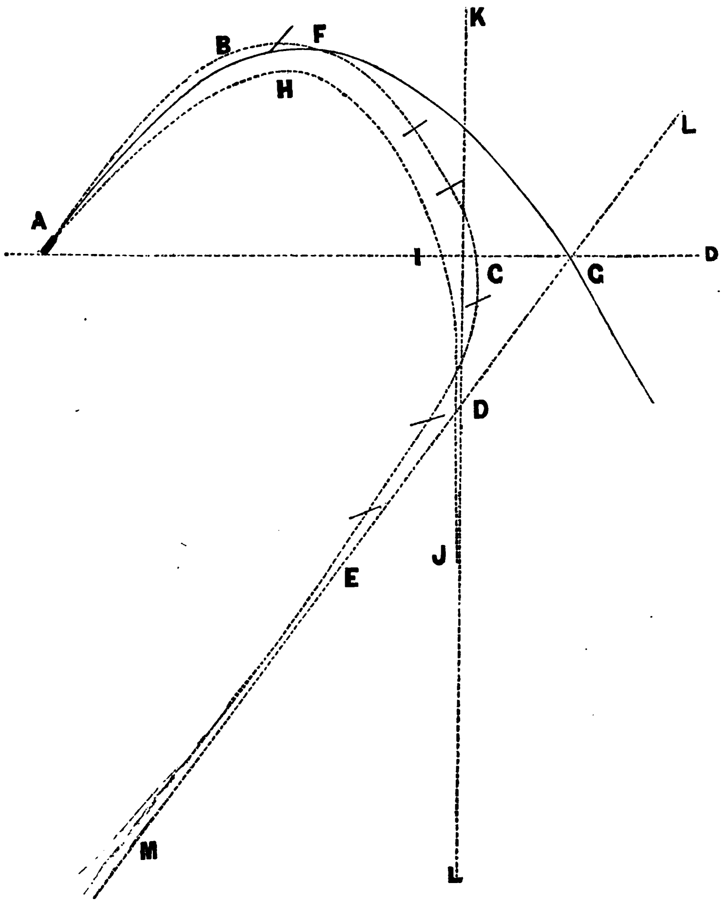
former case; consequently, the area B F J H Q B must be equal to the area B P G Q B. It was, therefore, evident, that the point J must lie outside the curve P G. This being so, it followed, that if the curve H J was prolonged backwards, the ordinate B M would be greater than B P; that was to say, the initial force of the slow burning powder, if not allowed to expand, would be greater than the initial force of instantaneous burning powder, doing the same work and calculated by the law above named. Hence it followed that, taking the same case as before, viz., the Whitworth large gun, the initial force of the powder, if it had not been allowed to expand, would have been greater than P B as determined for that case, viz., 24½ tons per square inch. How much greater, there were no means at present of knowing, because the position of the point D, when the powder was all burnt, could not be determined. The next remark was, that the slower the burning of the powder, the less was the effect produced with a given quantity. Taking the curve M J R H for instance; if the powder burned instantaneously, the work done would be the area B M J H Q B. If the powder was not all burnt until the ball arrived at D, the work done would be the area B F J R G H B. If a still slower powder was used, which did not all burn until the ball arrived at S, the work done would be only B F R H Q B. From this, the great loss of effect, caused by the use of slow-burning powder, was very obvious, and

if the same effect was to be obtained, it could only be accomplished by using larger charges. For instance, let there be two powders, one of which burned slower than the other. Let A B be the length of charge of the quick burning powder, and let it all be burnt when the ball had reached D; then the work done was B F J H Q B. If now the same work had to be done with a slower powder, a larger charge A C must be used, so as to obtain an area C O K I Q C equal to the area B F J H Q B; and this increased length of charge, required for slow powder, would be peculiarly inconvenient in the new system of guns, where the calibre was so much less, than for an equal weight of projectile, under the old system. That being so, it was with great surprise that he read, in the speech of the Secretary at War upon the Army estimates, on the 17th of March, 1860, a statement to this effect:—"That the last gun sent by Sir William Armstrong to be tried, was a 12-pounder, upon which the experiment was made, of firing forty rounds, with a charge of 1½ lb. of slow powder. These experiments showed, that they had been wrong in using powder of so quick a detonating nature for artillery practice, and especially for rifled cannon, which required a weaker and slower powder than in other cases." Mr. Longridge presumed the Right Honourable Gentleman would not have made that statement, unless upon authority. He thought, that if such were the case, although improvements might have been made in the construction of the guns, a retrograde step had been taken in the use of them. If the statement were true, it would be advisable to go to the Chinese, and to learn how to make good rifled cannon gunpowder. For his part, he believed the statement to be erroneous. It could not be otherwise, than that the more rapidly the powder was burnt, the greater must be the effect. He could only account for the desire for slow powder, by supposing that there was some fear lest the guns would not stand the great increase of work, which would have to be put upon them, if the rifled principle was carried out, to its fullest extent, with quick powder. It had been stated, that the Astronomer Royal entertained the opinion, that the strength of gunpowder was equal to 80 tons to the square inch. Upon hearing that, Mr. Longridge wrote to Professor Airy, and had received from him a reply to the effect, that it was the result merely of a rough mental calculation, and was never intended to be made public. He had since ascertained, that the divisor 2 had been omitted in the computation, which would bring the figure down to 40 tons instead of 80 tons; and even this, the learned Professor admitted to be based only on a very rough approximation.

He could not agree in the opinion, expressed by Sir William Armstrong, that the effect of a resisting medium was to prolong the range of the shot. No doubt the tendency of the resisting medium

was, at some portion of the flight, to raise the trajectory of an elongated shot, which preserved the direction of its axis, above what it would be, if the shot moved tangential to the curve. He had prepared a diagram in illustration of this, (Fig. 34).

Fig. 34.



Let A F G be the range of a projectile, in vacuo, from the gun A. Then the range, in air, of a shot moving with its axis tangential to its path, would be somewhat like A H I J; and would ultimately be asymptotic to a vertical line K L. But, if the projectile had such a spin, as to preserve the original direction of its axis of rotation, the action of the air on the under-side would be, to raise the trajectory above A H I, to some other curve A B F C, part of which might possibly be above the parabolic track. If so, it would

soon cross it, and as it lost its horizontal velocity, it would be more and more deflected back, till finally, the horizontal element of the resistance of the air would cause it to cross the trajectory of the tangentially-moving shot; and eventually, if no obstacle interfered, it would pass beneath the gun, in a curve asymptotic to a line L D E M. This result was easily proved, by a consideration of the forces. It was, therefore, seen, that the range of a spinning shot did not, in every case, exceed that of a tangentially-moving shot, this depending upon the position of the point of intersection of the two trajectories.

He did not believe that, in any case, the actual range could exceed the parabolic range, or the range in vacuo. He had calculated the parabolic ranges for some of the experiments made with the Armstrong and the Whitworth guns, and the results were:—

—		Elevation of Gun.	Actual Range.	Parabolic Range.	Difference.	Initial Velocity in Feet per Second
			Yards.	Yards.	Yards.	
Armstrong 12-pounder Gun.		7°	2,480	2,940	460	1,080
		8°	2,797	3,349	552	1,080
		9°	3,000	3,755	755	1,080
Whitworth Guns.	12-pr.	5°	2,342	3,057	715	1,300
		10°	4,120	6,020	1,900	1,300
	80-pr.	5°	2,604	3,057	453	1,300
		10°	4,730	6,020	1,290	1,300

In all these cases, the actual range was much below the range in vacuo, or the parabolic range.[1]

[1] In his remarks on closing the discussion, the President gave the following experiments, as corroborative of Sir W. Armstrong's assertion:—

Description of Gun.	Elevation.	Actual Range.	Initial Velocity in Feet per Second.
		Yards.	
Whitworth 12-pounder ..	2° 0′	1,252	1,300
Armstrong 12-pounder ..	1° 15′	840	1,080

Now the parabolic ranges in this case, taking into account the difference of level, would be:—

Whitworth gun .. .. .. 1,260 yards.
Armstrong gun .. .. .. 717 „

[The

To come now to the subject of the Paper, it would seem, from what had been said by some of the speakers, that what had been sought was altogether unnecessary, that cast iron was strong enough for the purposes of ordnance, and that no better material was required. There were two classes of opinions on the subject. With one it was the attachment to an old and faithful friend; with the other it seemed a more romantic feeling, delighting in the anticipated development of future excellence. One gallant officer had spoken, with great warmth, of his own experience of the good service done by the old cast-iron guns, and all must sympathise with him, to some extent, in his feelings of attachment to his old and trusty friend. Such feelings were very nigh akin to those which had so long enabled 'Brown Bess' to hold her ground, in spite of the refined graces of her more youthful rival. But he thought this class of admirers might be left with a passing acknowledgment to their constancy, and that attention might be turned to those who anticipated a great future for cast-iron guns. It had been said, that he had understated the strength of cast iron in putting it at 8 tons to the square inch. He had taken that as the average strength of cast iron in general. He believed, that in the inside of guns, it was not nearly so much. He had been rather astonished by the statement, that some experimental cast iron, which had been tested, was equal to a tensile force of 44,000 lbs. On inquiry, he found, that in that instance Acadian charcoal iron was used, and it seemed, that one specimen had borne nearly that force. But in the same page of the pamphlet, from which this high result was quoted, there were instances in which the tensile strength of the same iron was not quite 8 tons.[1] Mr. Longridge had referred

The last of these results was not at all conclusive; first, because a slight error in estimating the velocity would greatly affect the parabolic range, and secondly, because a very small error in elevation, at so low an angle, would also greatly vary the range. For instance, an error of only 15 minutes would extend the range from 717 yards to 972 yards. It was, therefore, quite possible that the anomalous result of the last experiment might be attributed to one, or both of the causes just pointed out.—J. A. L.

[1] Since making the above remarks, Mr. Longridge's attention had been called to the fact, that the specimen of iron, which bore under 8 tons per square inch, was of the first melting. The results of the different specimens tried are, therefore, given:—

First Melting.

		Tensile Strength.
1st.	One bar . .	16,973 lbs. per square inch.
2nd.	„ . .	19,271 „ „
3rd.	„ . .	24,227 „ „

Half Pig and Half Scrap from previous Experiments.

1st.	Mean of two bars . .	34·926 lbs. per square inch.
2nd.	„ „ . .	21·062 „ „
3rd.	„ „ . .	41·519 „ „

There was thus, evidently, a great variation in the quality of the iron.—J.A.L.

to one, or two documents upon this subject; and he found in the last Blue Book, (1858,) containing the Woolwich experiments, that the maximum strength of cast iron there tried, was 15 tons, and the minimum strength, 4½ tons, the average being 10 tons. Those experiments were made upon irons prepared, and sent specially by the makers, and doubtless, considered by them as the best for the purpose. The result of Mr. Hodgkinson's experiments, recorded in his edition of "Tredgold," showed an average tensile strength of 7 tons to 7½ tons per square inch; Low Moor iron being 6½ tons, and Carron iron, 6½ to 7 tons. From the Report of the "Commissioners on the use of Iron in Railway Structures," (1849,) it appeared, that the tensile strength of Bowling iron was 6 tons to 6¾ tons; and that of Low Moor iron 7 tons per square inch. He, therefore, thought, that he had not understated the strength, in taking it at 8 tons. It should also be borne in mind, that those irons which had the highest tensile strength, were less suited for ordnance, than those which, like the Low Moor and Bowling irons, had less power of ultimate resistance, but possessed more elasticity.

A great deal had been said, about the mixture of certain alloys; but he thought the present state of knowledge, upon that subject, was not such as to warrant them in looking for any great improvement in that respect. The increased density of iron had been spoken of as a means of improvement. All that Mr. Longridge would say upon that point was, that iron of a density of 7·3 was considered at Woolwich, unsuitable for gun purposes. He had been surprised by the observations which had fallen from the Chemist to the War Department, for whose chemical knowledge he had the highest respect. But, at the same time, he thought an undue importance had been attached to identity of chemical composition, as forming a guide to the mechanical properties of iron.

Many striking instances might be given to show, that identity of chemical composition might co-exist with great variation of physical properties. For example, phosphorus was a deadly poison, and ignited with the least friction in its ordinary state; yet in another state, without any change chemically, it might be swallowed without causing any injury, and did not ignite by friction. He believed there were certain compounds, such as one of chlorine and naphthaline, which existed in the gaseous, the liquid, and the solid form, and yet no chemical difference could be detected. Therefore, he did not think that chemical identity had much to do with the mechanical properties of iron. He was supported in that opinion, by the Report of a Committee of Chemists appointed in the United States, in 1849, to investigate this question. In 1851, their first Report was made, which was of a hopeful character. In 1852, it was reported, that a

decided relation, it was believed, had been observed between the amount of uncombined carbon and the tensile strength of the metal. But in the final Report, in 1855, all the former reports were withdrawn, and it was stated, that "though at first largely appreciating the extent of our labours, the completion of them sensibly diminished that estimate of their usefulness." Therefore, he thought, however desirable it might be to ascertain the chemical qualities of iron, practical men were yet very far from being in a position to accept them as indices of its tensile strength.

The next point was with respect to wrought iron. Mr. Clay intended, apparently, to object to the statement, made in the Paper, with respect to the deterioration of the iron on the inside of large forged-iron guns; but he merely took objection to the statement, and made no comment upon it. Now that statement having been taken from the writings of Mr. Clay himself, it could only be presumed, that when he recorded the facts, he had been satisfied as to the accuracy of what he had written. It had also been mentioned, that a new process of making guns had been discovered; and although the method was not communicated, it was stated, as a proof of its value, that a tube $2\frac{1}{2}$ inches in calibre, and 2 inches thick, was fired with a charge of $1\frac{1}{2}$ lb. of powder, twenty-two round balls, and a cylinder projecting 12 inches from the muzzle, without injury to the tube. In answer to this, Mr. Longridge would point to the tube represented in Figs. 14 and 15, (pages 312 and 313), which was 3 inches in diameter and only $\frac{3}{8}$ths of an inch in thickness; and which was fired with 2 lbs. of powder, under circumstances, described in the Paper, infinitely more trying than those now referred to. This cylinder, $\frac{3}{8}$ths of an inch thick, had been tested far more severely than the iron cylinder, 2 inches in thickness.

He had very little to say upon the subject of steel guns. Krüpp's steel had been alluded to, as possessing extraordinary tensile strength; and it was stated, that the accident to that gun was caused entirely by the nature of the projectile used in the trial. The form of shot shown in Fig. 19, (page 319,) had been ridiculed; but he begged to say, that it never had been his intention to use that shot, except for a particular experiment, and with a very small charge of powder. In his absence, it had been put into the gun with 2 lbs. of powder behind it, and the result had been the accident he had described. With regard to the form of shot used in Mr. Krüpp's gun, there was a wrought-iron hoop round the breech, and that hoop seemed to have shifted, sheared away the cast iron, and been jammed in the gun. He thought that such a shot ought not to have been fired with a heavy charge of powder.

Whatever material was used, it ought to be applied in the best possible manner, to enable it to do its full duty; and this was cer-

tainly not the case in a homogeneous mass. The attempt to cast guns hollow, and to cool them from the inside, had, he believed, been long since abandoned in the American arsenals. Several instances had been given of cast-iron guns which had shown great powers of endurance; but he would observe, that it was no proof of the sufficiency of cast iron, that a gun had been fired a certain number of rounds, with given charges. A cast-iron gun, if well made, and of uniform texture, did not fly to pieces all at once. It burst gradually, beginning at the inside by very minute cracks. It was quite possible that, for a certain time, these minute cracks might increase the strength of the gun. He would not detain the Meeting by going into a proof of this, but it might be received as a fact. These cracks gradually extended, and finally, the gun gave way. In fact, theory had distinctly shown the limit to which any homogeneous cylinder, or gun, could be strained, and he, for one, believed, that the indications of theory were the only sure guides to success.

He would now briefly allude to the principle, which it was the more immediate object of the Paper to bring forward. That principle, which had been adopted both by Captain Blakely and by Mr. Longridge, was, building up guns with concentric rings, or hoops, or binding them with wire. He was glad that the principle was no longer in the region of theory; but that facts might be referred to, as establishing the correctness of the means which Captain Blakely and he had, for so many years, entertained. Sir W. Armstrong and Mr. Whitworth had both adopted that principle in their large guns; but he was bound to say, he did not think it was being carried out by either of them, in the best way. In order to derive the full benefit from this mode of construction, it was necessary, that the rings should be put on at certain definite degrees of tension. The diagrams he had exhibited would illustrate the effect of not putting them on with the proper tensions. The theory of this principle had been worked out by a gentleman not unknown in this Institution,—Mr. C. H. Brooks,—to whom he was greatly indebted, as was also the Institution, and who had drawn up a very elaborate Memoir, containing the mathematical part of the question, which was given in the Appendix to the Paper.[1] The result of these calculations satisfied Mr. Longridge, that if the object was to obtain the utmost amount of strength from hoops, they must be put on with a certain definite tension. If that was not done, there would be risk of injury to some of the hoops, or rings of the gun. Mr. Whitworth had stated, that his method of putting on the hoops was by hydraulic pressure. This was one plan proposed by Captain Blakely, and was preferable to shrinking them on. Mr. Whitworth put them

[1] *Vide* Appendix, page 329, *ante*.

on with a great initial tension; in fact, with the utmost the material would bear without a permanent set; and consequently, the least increase of strain caused by the explosion would give them a permanent set. Thus, Mr. Longridge was convinced, that Mr. Whitworth not only failed to get the maximum amount of strength, but introduced an element of destruction into his gun. Sir W. Armstrong had said, that the hoops were put on hot in his gun. Mr. Longridge's experience in contracting on hoops showed, that it was impossible to ascertain the exact amount of tension, as no two pieces of iron would contract precisely alike; and it was only by accident, that the amount of tension, which theory indicated as necessary, could be applied. Therefore, though Sir W. Armstrong and Mr. Whitworth were both travelling in the right direction, he felt bound to say they were travelling without a chart, and were not following the sure indications of theory. In the Armstrong gun, the chase of the gun was made spirally, and welded up, and then upon that, at the breech part, there were other hoops made of iron, laid with the fibre longitudinally. Upon these the trunnion piece was shrunk, and over that again iron hoops, made spirally. Mr. Longridge thought, that the iron to resist the longitudinal strain should be placed outside, and he preferred to have it altogether independent of the gun; he believed it would stand the work better in that way. In the Armstrong gun, the whole of the recoil was dependent upon the adhesion of the longitudinally-laid tubes upon the other tubes. These might easily be affected by the concussion of repeated firing, more particularly, as they were not put on with any definite initial strain, and the result might be fatal to the gun. The Whitworth gun also depended on the adhesion of friction for the trunnions, and for longitudinal strength it was dependent on the inner tube. He must express his decided opinion, that large guns, of 8-inches, 10-inches, or 12-inches calibre, could not be safely made, by either of the methods adopted by Sir W. Armstrong, or by Mr. Whitworth.

It had been said, that the system he advocated would never be adopted by Artillery Officers. One of the objections to the system was, that there was no sufficient end-hold. He did not exactly understand what was meant by that expression, but he fancied it was as much as to say, that there were no means of fixing the ends of the wire. Now, nothing could be more simple. In the gun, (Fig. 15, page 313,) a small hole was drilled through the cast iron in a slanting direction; the end of the wire was put into it, and a wedge was driven in, so that there was no possibility of its uncoiling. In finishing off the end of the wire, the same plan was adopted; and a layer of solder was run along these coils, so that if two, or three, or even more, wires were cut, by any means,

the rest would not uncoil. It was further intended to protect these wires by a coating of sheet iron. The fixing of the breech, about which a great deal had been said, presented no difficulty. The material which transmitted the recoil was placed outside the gun. There was no difficulty in carrying out that system, and he felt satisfied, that ultimately, all large guns would be so constructed. With regard to the effect of temperature on wire-bound guns, he had calculated, that at 200°, the result would not diminish the tension of these coils more than $1\frac{1}{2}$ lb. or 2 lbs. There was, therefore, nothing to fear as to temperature. He was sorry to find, that Mr. Anderson did not like wire; and he would remind that gentleman, that only a few years ago he had an equal distaste for hoops. Having now so far changed his opinion as to build guns with hoops, Mr. Longridge was satisfied, that in a few years, Mr. Anderson would appreciate and acknowledge the superior merits of wire.

Mr. BIDDER,—President,—said, that the Institution might take credit for the very interesting character of this discussion, which was one of national importance; in fact, it had fully justified the observation, which he had made in his opening Address on taking the Chair;—that there was not any arena in this, or in any other country, so well calculated for the discussion of this class of subjects, as within the walls of the Institution of Civil Engineers.

The more immediate subject of the discussion, was the capability of vessels to resist great internal pressure, as proposed in Mr. Longridge's Paper. This had induced the question of the construction of guns, and the proposition to extend the range of the subject, had led to the interesting discussion which had taken place.

It must be admitted, that the theory propounded by Mr. Longridge, with regard to the tensile force of metal, had been satisfactorily demonstrated; and theoretically, the plan he suggested would appear to answer the intended purpose. Practical objections had, however, been fairly and legitimately urged against the proposed plan. These related chiefly to the difficulty of securing the ends of the wire, of strengthening the breech, and of forming the muzzle. How far the Author had succeeded in meeting those difficulties, the Members must judge. It was, however, evident, that he had established such a primâ facie case as should have entitled him to have received the attention of the Government, in his attempts to produce a light and efficient gun; especially when it was considered, that the subject was only now, for the first time, undergoing that careful scientific investigation to which its great importance entitled it.

There had been exhibited to the meeting two guns of the most scientific design and beautiful workmanship; the respective inventions of Sir W. Armstrong and of Mr. Whitworth. With regard

to the manufacture of the former, the President could not coincide with the opinions expressed, as to the difficulty of forging such guns. He had witnessed the operations, and as far as his experience went, he must say, that the mode of construction appeared to be most satisfactory, and he had no doubt, that the guns so constructed, in the new gun factory at Woolwich, possessed all the characteristics claimed for them. At the same time, from the general tenor of the discussion, it was evident, that there was a strong feeling in favour of the homogeneous metal used in the manufacture of the Whitworth gun, and in that opinion the President participated. The metal certainly possessed the characteristics claimed for it; it was nearly as hard as steel, and as tough as copper, and as a material for artillery, what more could be desired? Cast-iron guns had, no doubt, occasionally, exhibited wonderful results. They had withstood an immense amount of firing and strain; but there was not any certainty of uniform results being obtained. In one case, a cast-iron gun had sustained fifteen hundred, or two thousand rounds, whilst another gun, stated to have been cast from the same metal, and under precisely the same conditions, had not resisted for a single day. This was one grave objection; whilst the great weight of cast-iron guns must also, in the present day, be a formidable objection to the use of that material, either for field guns, or for naval armament. In the production of artillery, the first cost ought not to be weighed against attaining the greatest efficiency, combined with the utmost saving of weight; the latter he considered a point of primary importance. In the field it was imperative, both on account of the rapidity of manœuvring now required, and to facilitate the transport, at considerable speed, over a rough country; and on board vessels of war, carrying an armament of one hundred and forty guns, the saving of weight must, evidently, be of the most material consequence. The rifling of cast-iron guns might have been a very proper subject for consideration, some twenty, or thirty years ago; and no doubt, blame must attach somewhere, that it was only within the last few years, that the rifling of ordnance had been seriously thought of, or had been practically tried.

In making a few remarks upon the practical results of trials, and on the present practice of gunnery, the President begged the Members to receive the calculations which he should present, and the results which he should submit to them, as mere approximations. There had been communicated to him, the results of an immense number of experiments in gunnery, and upon testing them he had found, that, to a great extent, the results were not such as could entitle them to implicit reliance. He did not mean by this, to say that apparent facts had been garbled, or misrepresented; but circumstances which had attended the experiments,

but which had been omitted, had influenced the results, and thus rendered them useless for the purposes of investigation. Circumstances had occurred, which convinced the President, that he had made very little progress in the science of gunnery; a few weeks ago, he thought that he was on the eve of ascertaining some definite results, but he now felt, after more careful investigation, that, far from being at all advanced in the science, the threshold was only just reached, and that scarcely anything was really known of that important science. The very first thing in gunnery, but upon which the authorities were not agreed, was the initial pressure of gunpowder, and its 'modus operandi' upon the shot. Upon that subject the most discordant opinions prevailed. What he meant by the initial pressure of gunpowder gas was, the pressure of the gases evolved on the explosion of gunpowder, when confined within the actual space allotted for the gunpowder itself. That was what must be arrived at, in order to make the calculations as to the effect produced, considering also the circumstances under which the powder was exploded. In the course of the discussion, Captain Boxer, who occupied a high position in the Royal Arsenal, at Woolwich, and who claimed to have considerable information relative to the explosion of gunpowder, and the requisite strength of metals to resist its force, stated, that the forces of gunpowder gas were of two distinct kinds,—statical and percussive. Now from this proposition, the President must distinctly beg to differ. Statically, a pound of gunpowder gas, would not have more effect, in generating velocity, than a pound of butter; and if it acted percussively, it must destroy both the projectile and the gun.

In the work of Mr. Lynall Thomas[1] it was stated, that gunpowder had some mysterious action; that before the gases acted upon the shot, there was some kind of undulation, or oscillation, which, by some means, communicated an initial velocity to the shot, irrespective of their expansive action. Mr. Treadwell,[2] again, stated, that the whole force of gunpowder was due to the inertia of the shot, or of any mass with which it was placed in contact, at the moment of explosion; and he, moreover, said that a large charge of gunpowder, if exploded in vacuo, would not burst a sheet of tissue paper. From that position, it was scarcely necessary to record an unconditional dissent. All the phenomena attending the explosion of gunpowder, could be explained by simple mechanical effects. If it was assumed, that in exploding gunpowder

[1] *Vide* "Rifled Ordnance; a Practical Treatise on the Application of the Rifle to Guns and Mortars," etc. By Lynall Thomas. 8vo. London, 1859.

[2] *Vide* "On the Practicability of Constructing Cannon of Great Calibre," etc. By D. Treadwell. Tract, 8vo. Cambridge, 1856. (From the Memoirs of the American Academy.)

in a vessel, the resulting gases derived their force from the pressure of a column, 100,000 feet in height, of a uniform density, it would be found, that all the subsequent effects observed could be satisfactorily accounted for. In general, the element of time was completely neglected. Now in explosion, gunpowder produced initially the same pressure, whether in a gun, or in vacuo, or in the atmosphere; but in a gun, the inertia of the shot compelled a longer time to be occupied in exploding the powder. In the open air, the same quantity of powder exploded with immense rapidity, and the pressure was no sooner formed, than it was lost by expansion. For instance, in the case of an 80-lbs. rifled shot, the velocity of 800 feet per second was communicated in the three-hundredth part of a second; and in the case of a rifle bullet, the same velocity was acquired in the three-thousandth part of a second. From this statement some conception might be formed, of the very minute elements which were imported into the consideration of the question, where time alone gave the necessary explanation of all those phenomena, which were exhibited by the explosion of gunpowder. The President had tested the initial power of the gases by the mechanical effect, *i. e.* by the velocity with which the shot quitted the gun. It was assumed, which was not, however, correct, that all the powder exploded instantaneously. Under those circumstances, it required a pressure of nearly two thousand atmospheres, to generate the initial velocity. He then supposed it to explode, so that a constant pressure was maintained throughout the length of the gun. This would indicate, that the initial pressure could not be less than five thousand atmospheres. Therefore, he was unable to arrive at the conviction, that the initial pressure of the gunpowder was so low as three thousand atmospheres, or 20 tons to the inch. There was also another element to be considered; the enormous loss of the explosive power in following the shot, and in the loss of the caloric by the expansion of the gases. Assuming the tension of the gas to represent a column 100,000 feet in height, the velocity at which gas of that height would flow into vacuum, would be 2,500 feet per second. When the velocity of an 80-lbs. shot was 800 feet per second, the effect was, that the power of the gases was then reduced to a column which represented the difference of the velocity; a column which produced the velocity of 1,700 feet per second, (*i.e.* 2,500 − 800,) was two-fifths of the whole column; so that before the shot travelled 16 inches, the velocity of the gas, besides being reduced, by the space it occupied, to one-half, was further reduced three-fifths, or 60 per cent. Therefore, as to the mechanical effect of gunpowder, the result could not be produced, unless the initial force of gunpowder was much higher than three thousand atmospheres.

It was curious, although, perhaps, not germain to the subject, to compare the mechanical effect of 1 lb. of gunpowder with that

of 1 lb. of coal. In the Whitworth 3-pounder gun, the initial velocity was 1,300 feet per second, and that was generated in the two-hundredth part of a second. The mechanical effect was measured by the shot being elevated 26,000 feet, which was represented by 1 lb. raised 78,000 feet, and that was done in the two-hundredth part of a second. A nominal horse-power was represented by 33,000 lbs. raised 1 foot high per minute, or $2\frac{3}{4}$ lbs. in the two-hundredth part of a second. Therefore, the work performed by 8 oz. of gunpowder was represented by 28,000 H.P. The 8 oz. of powder, in the two-hundredth part of a second, represented 4,000 tons a-day. An engine of 28,000 H. P., working twenty-four hours would consume 1,200 tons of coal, so that 1 lb. of coal achieved the result obtained by 3 lbs. of powder.

The next element for consideration was that of atmospheric resistance. The only well-recorded experiments were those of Dr. Hutton;[1] they were made with immense care and research, and if the mechanical appliances of the present day had been at the command of that distinguished man, the theory of gunnery would have been in a very different state from what it now really was. But the best appliance for his experiments was a 1-pounder gun, made expressly for his use. The experiments were tried in Galleons' Reach, a part of the River Thames, about 800 yards wide. Cadets were posted along the banks, on each side of the river, to take notes of the flight of the shot, along the water; it was however found, that the shot did not travel in the presumed line of fire, frequently passing over the heads of the cadets, first on one side of the river and then on the other, and that the only chance of hitting an object, 1 mile distant, was by aiming some 400 yards either to the right, or to the left of the target. This was owing to the windage of the shot in the gun, causing it to travel from one side to the other, according to chance. Still, all these difficulties were struggled against, by Dr. Hutton, and all who wished to have their minds imbued with the difficulties of the question, should examine the details, and go through his calculations. The velocity of the shot was determined by the balistic pendulum, whilst the atmospheric resistance was ascertained by revolving machinery, and the result established the enormous resistance of the atmosphere, of 102 lbs. upon a 1-lb. shot, 2 inches in diameter, travelling at a velocity of 2,000 feet per second; at 1,300 feet per second, the resistance was $42\frac{1}{2}$ lbs.; and curiously enough, it would appear, that the actual resistance of the atmosphere was nearly that which would be due to the impression of wind, upon a disc of the same diameter and at the same velocity.

The resistance of the atmosphere was due to three causes; viz., the displacement of the atmosphere, the friction of the atmosphere

[1] *Vide* "Tracts on Mathematical and Philosophical Subjects," &c. By C. Hutton. 8vo. Vol. III. Tract 37. London, 1812.

upon the periphery, and the back pressure, which was the vacuum formed in the rear of the shot, and which it was necessary for the atmosphere to fill up again. The latter did not follow the ordinary law of the squares, and it was believed, that in all cases of spherical shot, it was increased beyond what theory gave; for it was assumed, that the air adjacent to the path of the shot was in a quiescent state, and was ready to fill up the vacuum. But when the shot expelled the atmosphere, it was driven off in lines tangential to the periphery, so that the force must be more intense, as it had, not only to change the direction of the particles, but to retard their motion, before they flowed into the wake left by the projectile. The result had been to establish, that the experimental resistances were nearly double the amount derived from theory.

It was owing to the enormous resistances occasioned by the atmosphere, that Dr. Hutton, following in the track of Robins, was induced to recommend, as the only remedy, the use of elongated projectiles. This, of course, could only be effected by rifling, and thus insuring the correct flight of the shot.

With regard to rifling, the remarks might be confined to the two systems respectively adopted by Sir W. Armstrong and by Mr. Whitworth; the former by impressing the rifle grooves on the soft-metal covering of the projectile; and the latter, by fitting the hard-metal shot to a polygonal-shaped bore.

The elongated projectile reduced the enormous resistance of the atmosphere, in several ways. In the first place, there was more momentum according to the area. Comparing the 1-pounder gun, 2 inches in diameter, with the Whitworth 3-pounder gun, 1½ inch in diameter, the surface exposed to resistance was nearly double in the former, to that of the latter, besides which there was a momentum of nearly 3 to 1 in respect of their relative weights; reducing resistance in the proportion of nearly 6 to 1. By careful experimental trials, and by giving to the front of the shot a sharper form than the hemisphere, a still greater reduction in the total amount of resistance had been attained. In order, however, to produce the greatest effect, *i.e.* to elongate the projectile to the utmost extent, it was necessary to determine the proper limits of rifling. Upon this point the President did not agree, either with Sir William Armstrong, or with Mr. Longridge, in thinking that the amount of twist was immaterial. On the contrary, he thought it most material; because upon the extent of the twist depended the power of using long, or short projectiles; especially considering, also, how small an amount of power was absorbed in giving the necessary twist. Mr. Longridge had stated it to be about one-fortieth part of the power necessary for generating the velocity of the shot, inclusive of the power absorbed by the friction; but the result of the President's own investigation of the 3-pounder gun was, that the twist given, required only the one hundred and seventieth part

of the force which was necessary to give the requisite initial velocity to the shot.

In testing the experiments, the most convenient system was, to ascertain the ratio of the velocity of the retardation of the shot, per element of distance, rather than per element of time. Theoretically and practically, it appeared, that the retardation, in passing through equal spaces, was a fixed proportion of the velocity. For example, if a shot going 1,000 yards per second, lost 10 feet of velocity in a certain space; then with a velocity of 500 yards per second, it would lose 5 feet of velocity in the same space. These statements must, however, only be received as approximations; for the reliable experiments had, hitherto, been so few, that no one could be justified in making an exact statement upon the subject. They must be further carried out, with the assistance of the electric telegraph, both for time and range, so as to enable the initial velocity to be determined beyond all doubt.

Having made these remarks, the President proceeded to give a few details of the results of some recent experiments, in order to show what had been accomplished by rifling.

The first examples were with

SPHERICAL SHOT.

Weight.	Diameter.	Charge of Powder.	Elevation.	Initial Velocity.	Actual Range.	Parabolic Range.
lb.	Inch.	oz.	Degrees.	Ft. per sec.	Feet.	Feet.
1	1·96	4	15	1,234	4,660	25,000
		8	15	1,644	6,066	44,000
3	2·78	..	20	1,200	4,800	31,200
		..	30	1,200	7,680	45,000

It would be seen, that the parabolic exceeded the actual range, in a proportion varying from five-fold to seven-fold.

The next results were with

THE WHITWORTH RIFLED CANNON.

Weight of Projectile.	Diameter across the Flats.	Length of Barrel.	Twist, one turn in Inches.	Charge of Powder.	Initial Velocity.	Number of revolutions per Second.	Elevation.	Actual Range.	Parabolic Range.
lbs.	Inches.	Inches.			Ft. per sec.		Degrees.	Feet.	Feet.
3	1½	72	40	8 ozs.	1,300	400	3	4,707	5,550
							10	12,567	18,300
							20	20,970	34,500
							35	28,740	49,200
12	3¼	93	60	28 ozs.	1,300	260	2	3,756	3,780
							5	6,960	9,210
							10	11,739	18,300
80	5		100	12 lbs.	1,300	156	5	7,722	9,200
							7	10,476	12,900
							10	13,665	18,300

Comparing the experiments with the Whitworth 3-pounder gun, with those of the 1-pounder gun, used by Hutton, the following would be the results:—

The charge of powder was one-sixth in place of one-half the weight of the projectiles, and the elevations were 10° and 15°, respectively. The initial velocity of the rifled shot was one-fourth less than that of the round ball; and yet, with a lower elevation, the range of the Whitworth projectile was more than double that of the spherical shot; whilst the parabolic range exceeded the actual range by only 50 per cent. in the former, as compared with 600 per cent. in the latter case.

Now the difference of these results must be attributed to the fact, of the spherical 1-lb. shot losing 15 per cent. of velocity in 100 yards of flight; whereas the 3-lb. shot, from the Whitworth gun, lost only two-thirds per cent., or less than one-twentieth of the former. In other words, the resistance of the 3-lb. shot was only one-twentieth of that of the 1-lb. spherical shot, which was partly due to the less surface presented by that form of shot, to the resistance of the atmosphere. It had been stated by Sir John Burgoyne, that for breaching a fortification, the old service guns could not be surpassed, because the projectiles possessed so high an initial velocity. That was quite true, as far as it went; but it must be borne in mind, that after the first 500 yards had been traversed, there was so great a reduction in the velocity of the spherical shot, as to equalise its velocity with that of the rifled shot, which latter very nearly maintained its initial velocity; whilst from its form, its power of penetration was, *cæteris paribus*, in excess of that of the spherical shot. It was, moreover, a fact, that a rifled shot, at the distance of a mile, was as effective against a wall, or any other object, as a 68-lbs. spherical shot, at a distance of 500 yards; therefore, even for breaching purposes, the great advantage of rifling must be apparent.

The next examples were in connexion with

THE ARMSTRONG GUN.

Weight of Projectile.	Diameter.	Charge of Powder.	Initial Velocity.	Elevation.	Actual Range.	Parabolic Range.
lbs.	Inches.	oz.	Ft. per sec.		Feet.	Feet.
				4° 26′	4,500	4,860
5	..	..	1,000	6°	5,892	6,600
				11°	9,000	12,000
				7°	7,440	9,300
12	3	24	1,100	8°	8,400	10,660
				9°	9,000	11,880

The above experiments showed, with all deference to Mr. Long-

ridge, that there were proofs of the actual range being all but identical with the parabolic range, at low elevations. Sir William Armstrong had alluded to a new element, and it was by that new element, that those effects were produced; viz., the angle between the axis and the path of the projectile, increasing, therefore, with the angle of elevation. The diagram, (Fig. 34, page 441), exhibited by Mr. Longridge, illustrated this hypothesis, that a shot fired at an elevation of 2°, would, towards the end of the range, meet the atmosphere at an angle of 4°; and resolving the resistance of the atmosphere at that angle, into a vertical elevation, it would be found to be ½ lb. on the 3-pounder projectile. The result, therefore, would be, that from the letter F upon the diagram (Fig. 34), the line of the curve would be straightened off, and the ultimate course of the shot would be nearly straight, at the end of its flight.

In comparing the present results of the Whitworth and the Armstrong guns, as far as experiments had hitherto shown, there was a difference in the initial velocity of between 200 feet and 300 feet per second, in favour of the former. As regarded elevation, that was important, particularly with respect to accuracy of fire. When Sir William Armstrong made his observations with regard to the long range, the President could hardly agree with him. But that was not the main object. The practical object of attaining exceedingly long ranges, must be for attacking any fortified place, or for bombarding a naval arsenal, so as to be able to fire all day and night, still keeping out of the reach of the enemy, and to drop shots and shells, with impunity, into apparently inaccessible places, so as to cause, if not absolute ruin, at least very considerable annoyance in any naval arsenal, or maritime establishment. It was a very material element, to be able to lower the elevation, as by that means, the accuracy, of the firing was increased, or a longer range attained with the same elevation. Thus, for instance, with 2° of elevation, the range, with a velocity of 1,000 feet per second, would be 730 yards; with 1,300 feet per second it would be 1,230 yards; with 1,500 feet per second it would be 1,620 yards; the latter velocity giving the same accuracy, at double the range, which the initial velocity of 1,000 feet could command.

Objections had been raised to Mr. Whitworth's mode of breech-loading, as being exposed to injury from shot. But did not the trunnions of every gun offer quite as great projection, on both sides of the gun, as the hinge did on one side? On the other hand, it had been objected, that Sir William Armstrong's gun did not admit of a choice in the variety of the projectiles. It had also been objected, that the Armstrong gun was not adapted for firing red-hot shot, or shot filled with molten metal. Also, that the Armstrong projectile could not be fired from the Whitworth gun.

There could not, however, be any doubt, that the ingenuity which had enabled Sir William Armstrong to design that very beautiful gun, would also enable him to overcome such difficulties with regard to the projectiles. These objections only induced the conviction of the paramount importance of a combination of the two systems, propounded by Sir William Armstrong and by Mr. Whitworth, which would, undoubtedly, produce a most perfect weapon. The exertions of both those gentlemen had considerably added to their reputation, and their sacrifices and devotion of their time in the service of the public, deserved the highest encomiums.

Mr. Longridge had made a remark with regard to the statement by the Minister of War, a short time since, upon the subject of gunpowder. Upon the authority of Sir William Armstrong, the President might state, that what was intended to be said was, not that Sir William Armstrong could not use more powerful powder, as in fact, he could advantageously use powder of any strength, but that in experimental firing, it had been found, that more regular practice was obtained by using slow-burning powder.

Very little had been said upon the subject of muskets. Now it was of equal importance, that all the branches of the service of this country, should be provided with the most efficient weapons. The great contest had, hitherto, been between the Enfield and the Whitworth rifles. With regard to the former, it was impossible to say how the adopted twist had been arrived at, or how the diameter of the bore had been fixed. The President had carefully examined the experiments with that rifle. The shots fired from the rest, which ought to have been the most perfect, were entirely devoid of accuracy; but when the rifles were fired from the shoulder, and individual skill was imported into the trials, the practice was very much improved. The Enfield rifle might be the proper weapon, but certainly very little, if any, scientific acumen was exhibited in the selection. It must, however, be generally admitted, that the Whitworth rifle, both for length of range and accuracy of firing, was vastly superior to the Enfield; and if there was any small difference in the cost of the two weapons, it ought not to weigh one moment in comparison with efficiency. Every soldier in the service cost the country from £50 to £100 for his education, and £50 a-year for his maintenance, and to hesitate upon a question of five, or ten shillings, or even ten pounds in the cost of the weapon, to arm the soldier, appeared to be carrying economy in the wrong direction. Within the last few weeks, the President had made some experiments with Mr. Whitworth's rifled musket. Those experiments were made with paper screens placed at distances of 50 yards from each other, throughout the length of Mr. Whitworth's gallery. The height was taken from a fixed level, to where the shot passed through each screen successively, and, the fall of the shot being

thus ascertained, the velocity at each interval was deduced. The experiments were satisfactory; but phenomena were observed, which required to be elucidated by further experiments. Judging from the fall of the shot, from the line of elevation, in the first 50 yards its velocity was only one-half of its subsequent velocity, and instead of falling only $2\frac{1}{2}$ inches below the line of fire, in 50 yards, it fell $7\frac{1}{2}$ inches in that space. The following results were obtained in a range of 500 yards:—With a rifle of 0·442 inch calibre, and 39 inches long in the barrel, the charge of powder being 70 grains, and the weight of the projectile 530 grains, the initial velocity was 1,300 feet per second, at an elevation of 1° 26′. With the same trajectory and a similar projectile, but with a charge of powder of 100 grains, the initial velocity was 1,400 feet per second, at an elevation of 1° 8′. With a rifle of the same diameter, but 33 inches long in the barrel, the charge of powder being 50 grains and the weight of the projectile 530 grains, the initial velocity was 1,200 feet per second, at an elevation of 1° 40′.

These results confirmed what had been stated, with respect to cannon, that as the elevation was increased, the greater was the amount of retardation during the passage through the air, which was owing to the greater angle at which the axis of the shot met the atmosphere in its path. As regarded rifling, there was no evidence in what way the twist could generate error, whilst it was admitted, that at the same time, it gave immense range to the projectile; therefore, it appeared, that short of what might be found inconvenient in the manufacture, there was not any limit to the twist of the rifling of a musket barrel.

In conclusion, the President would make a few general observations which must have occurred to all who had followed the discussion. Seeing for how long a time gunnery had been known, and what enormous interests were at stake, it did appear extraordinary, that in the year 1860, there were only, as it were, indications of beginning fundamentally the proper study of the subject, although owing to the ingenuity of Sir W. Armstrong and of Mr. Whitworth, the mechanical appliances appeared to be approaching near to perfection. There must be some error in the systems of all Governments, because neither in this, nor any other country, had any marked improvement, or decided progress taken place. The reason for this might be chiefly attributed to the unjust manner in which that distinguished branch of the service, the Royal Artillery, had been treated, by the governing powers. The officers were required, or expected, to be perfect in the science and practice of gunnery, so as to be able to conduct their operations, under the most terrible circumstances and under conditions of the most disturbing character. Besides which, they were expected to be acquainted with the mechanical branch of the science and even

to construct guns and projectiles, although they could not have had any opportunities of acquiring mechanical knowledge. The education of the artillery officer for conducting his routine duties, and in acquiring the power of enforcing military discipline, was the least adapted for qualifying him for the performance of mechanical duties; therefore, his education ought, hereafter, to be conducted on different principles, more especially as the powers of the weapons, which he would have in charge, would be so much enlarged as to demand more careful cultivation, than had hitherto been necessary. This duty ought to be confined to obtaining complete mastery over the weapon that was placed in his hands; and his experience would then enable him to judge of the merits and demerits of the mechanism of the guns, and thus to indicate to the mechanician, that which should be preserved and that which it was desirable to correct. If, however, in addition to these duties, the artillery officer was called upon to organise factories, and to superintend the construction of guns and projectiles, the demand was such as no ordinary human being could adequately respond to. It was owing to this system, no doubt, that such slow progress had been made in gunnery. It was owing to this, also, that until very recently, guns were bored by means of horse machinery at the Royal Arsenal, at Woolwich, whilst in almost every petty workshop, steam machinery was concurrently employed. It was owing to this, that a highly talented mechanician had been wasting his time in merely managing a gas work, until he had been, literally, 'dug out,' to be placed at the head of a great public establishment, where there was scope for the exhibition of his powers. It was owing to this, that the year 1860 had overtaken the Government, before anything had been realised in the true science and practice of gunnery, although, thanks to Whitworth and Armstrong, the mechanical department was fast approaching perfection.

The Emperor Napoleon III., in the preface to his admirable treatise on the "Past and Future of Artillery,"[1] had offered an explanation on this subject. He said, that the progress of artillery had to contend against two "ennemis redoubtables, les innovations imprudentes et la routine." He remarked: "Inventions that are before their age, remain useless, until the stock of general knowledge comes up to their level." Again:—"Whatever is complicated, fails in producing good results in warfare; the promoters of systems forget, always, that the object of progress ought to be, to obtain the greatest possible effect, with the least possible effort and expense." He, however, laid the greatest blame on the opposition of routine,

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[1] *Vide* "Œuvres de Napoléon III." Paris, 1856. Tome IVme. "Du Passé et de l'Avenir de l'Artillerie: avant-propos," pp. 15, 17. The Preface is dated, Fortress of Ham, May 24, 1846.

"which, being enamoured with old ways, has preserved for ages, practices that are most stupid." And "not only does routine scrupulously preserve, like some sacred deposit, the errors of antiquity, but it actually opposes, might and main, the most legitimate and the most evident improvements."

Although the Government was really beginning, in 1860, to stir in the matter of artillery, yet in point of ship-building the state of the public establishments was scarcely advanced beyond that of the year 1760. There were still in construction, ships to carry, in some cases, one hundred and forty guns, with a full conviction that half a dozen of the projectiles, such as were now made, would destroy any one of those vessels.[1] They could never be brought into a position to use that vast armament effectually, against a fast steamer powerfully armed, or to bear upon a fortress. As to line-of-battle ships, their time had evidently gone by; because the conditions which enabled them to range alongside and to bombard each other, were entirely changed. Fighting at sea would become something like American duelling,—dodging after each other, and seeing who could get the first, or best shot:—in such manœuvring, the advantage would, evidently, be in favour of the fastest vessel.

In America, they were building corvettes to carry only ten, or twelve very heavy guns, with enormous engine power, to attain a higher speed than anything the Royal Navy of this country possessed. With such advantages of speed, having guns only on the upper deck, and having means and appliances for working them, which could not be obtained with the present crowded armaments, the conviction must be induced, that the Royal Navy of England would yet have to be reconstructed.

In conclusion, the President would express a hope, that either during the present Session, or early in the succeeding year, this question of the science of gunnery would be re-opened, with more assured data than had been brought forward on the present occasion.

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[1] The recently published statement of the increasing liability of large ships, to strain and to become leaky, clearly proves the necessity of some change, either by the reduction of the present armaments, or by introducing guns of lighter construction.—G. P. B.

McKenzie and Wentworth's Breech-loading Rifles.

After the Meeting, Mr. W. Strode, (Assoc. Inst. C.E.,) exhibited specimens, and explained the action, of Messrs. McKenzie and Wentworth's breech-loading rifles.

The conditions sought to be fulfilled in these rifles were:—

1st. That they should be able to take the present ammunition.

2nd. That they should have a sound joint at the junction of the breech and the barrel.

3rd. That there should be nothing liable to be discharged against the soldier himself, by his own act, in case of the bursting of the rifle; and, therefore, no plug, or stopper to be put in from the back, or breech end of the barrel.

4th. That the strength should not be less, and the weight scarcely more, than in the present guns.

5th. That the moveable breech should be capable of adaptation to any barrel, as well as to any form of ammunition.

He stated, that these rifles only differed from those of the Enfield pattern, in the breech and in the stock; so that, if the changes were made which these alterations involved, they could be readily manufactured at the Government establishment at that place. It was thought, that such a weapon would be especially useful for Volunteer Rifle Corps, as muzzle-loading would not be necessary.

February 21 and 28,
and March 6, 13, and 20, 1860.

GEORGE PARKER BIDDER, President,
in the Chair.

The discussion upon the Paper, No. 1,014, "On the Construction of Artillery, &c.," by Mr. J. A. Longridge, occupied the whole of these five evenings, to the exclusion of any other subject.

At the Meeting of March 6, the following Candidates were balloted for, and duly elected:—Alexander Bassett, as a Member; William Beardmore, Thomas Brown, R.N., John Wiltshire Clarke, Henry Lee Corlett, Nathaniel Grew, James Lovegrove, Joseph Phillips, Emanuel Roberts, Charles Ritchie Walker, and Charlton James Wollaston, as Associates.

March 27, 1860.

GEORGE PARKER BIDDER, President, in the Chair.

No. 1,010.—"On Combined Steam."[1] By the Honourable JOHN WETHERED, United States.

In this age of progress and improvement, there is, perhaps, no branch of science which has more occupied the attention of scientific men, than the application of steam, an agent which has tended so much to ameliorate the condition of mankind, by decreasing the cost of production, by economising time, and by extending commercial relations throughout the world. In looking at the many improvements for generating steam in boilers, by which the heat from the furnaces is, apparently, brought, as closely as possible, into contact with nearly every particle of the water, it might be supposed, that as much heat is utilised as is practicable. And in examining the mechanism of the engine, by which the required motions are so much simplified, it might also be supposed 'that no great improvement could be made in that direction. By these improvements, steamers have acquired a rate of speed which, a few years ago, would have been deemed fabulous. They have also performed voyages of such extent, as to falsify the predictions of the philosophers, who, a few years since, asserted, that it was impossible for a vessel to carry sufficient coal to steam across the Atlantic.

Notwithstanding the existing rapid steam communication between the several commercial nations, the present progressive race of men, particularly the Anglo-Saxon portion of them, is restless and desirous of travelling at a still greater speed. Governments have caught the infection, for, in renewing ocean mail contracts, greater speed is demanded, even at largely increased subsidies. Few persons not belonging to this and similar associations, are aware of the great additional cost of obtaining an increase of speed. For example, a steamer of 3,000 tons burthen, assuming the consumption of fuel to be only $4\frac{1}{2}$ lbs. of coal per

[1] The discussion upon this Paper occupied portions of two evenings, but an abstract of the whole is given consecutively.

indicated H.P. per hour, will consume, at the several rates of speed, the following number of tons of coal, per day:—

Speed, per hour	. Miles	10	11	12	13	14	15	16	17	18	19	20
Coal, per day .	. Tons	46	62	80	102	128	157	191	228	271	319	372

To obtain an increase of speed of only 10 per cent., requires an increased consumption of fuel of nearly 50 per cent.; to double the speed would require eight times the quantity of fuel. The great desideratum appears to be, to obtain increased power, or economy in the consumption of fuel, without the great commercial disadvantage of occupying increased space, by enlarging the dimensions of the boilers and machinery.

The object of this Paper is to call attention to a system of applying steam, by which this desideratum is accomplished. It consists in the application of ordinary and superheated steam, mixed. The mode adopted to carry out the system, is, in addition to the ordinary pipe by which the steam is conveyed to the cylinder, to attach another pipe to the boiler, for conveying the steam to be superheated to pipes, or other contrivances, placed in any convenient form near the fire, or in the up-take, or chimney of the boiler, or in a separate furnace. The superheated steam is thence conveyed by a pipe, which is joined to the ordinary steam pipe at, or before its entrance, into the cylinder. In its passage through the superheating apparatus, this portion of the steam is heated to 500°, or 600° Fahrenheit, by the waste heat. The heat, thus arrested, is conveyed to, and utilised, in the cylinder, by its action on the other portion of steam from the boiler, which is more, or less saturated, according to circumstances. The combined steam is used in the cylinder, at from 300° to 450° Fahrenheit, instead of at the low temperature, at which steam is generally employed. The effect of the two kinds of steam is, that the superheated steam yields a portion of its excess of temperature to the ordinary steam, converting the vesicular water which it always contains, into steam, expanding it several hundred-fold; whilst, at the same time, the ordinary steam yields a portion of its excess of moisture, and converts the steam gas into a highly rarified elastic vapour, in other words, into pure steam at a high temperature. Experience has proved, that the employment of the combined steam produces a mechanical effect superior to that from steam as ordinarily used, or steam gas, as superheated steam has been properly termed by Professor Rankine.

Since the introduction of the Author's system into England, and its successful application, four years ago, to the Admiralty

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yacht, the 'Black Eagle,' and subsequently, to several other steamers, endeavours have been made to employ steam simply dried, or superheated. But this is only an attempt to galvanise the corpse of an obsolete system. It has been repeatedly tried in England, France, and America, and it has been, in all cases, abandoned. To superheat steam partially, will result in a certain degree of economy; but to obtain the full power and economy from its use, it is absolutely necessary, that it should be heated to a high degree of temperature, when it assumes the state of a dry gas, which absorbs the lubricating materials, and, consequently, destroys the packing and the rubbing parts of the machinery. This is the inevitable result, which has rendered its use of no permanent commercial value. It follows, that when all the steam from the boiler is superheated, its temperature must vary, in proportion as the heat of the furnaces varies; the temperature of the steam in the cylinder is, therefore, beyond the control of the engineer. It is well known that, at times, it is extremely difficult to generate a sufficient supply of steam for the engines. When this is the case, 'hard firing' is resorted to, which suddenly raises the temperature of the steam to such a dangerous degree, that it damages the machinery. There are two steamers now in the Victoria Docks, whose cylinders and slides have been so far destroyed, by the use of superheated steam, as to require to be re-bored and re-planed. It was the consideration of this difficulty which led to the discovery of the system of employing mixed steam. Independent of the fact, that the mere mixing of the two kinds of steam produces a new motive power, superior to, and more economical, than the use of either, separately, it is a pure vapour of highly expansive force at a high temperature, which is entirely under control, by merely turning a valve, and can be so regulated, as to produce the greatest mechanical effect, with the most perfect lubrication to the slides and cylinders. This is the main advantage which it possesses over all other applications of steam. Another is, that, as the supply of steam to the cylinder is conveyed through two channels, if any accident should happen to the superheating apparatus, the connection with the boiler is cut off, by merely closing the supply valve to it, and the cylinders can be worked with plain steam alone. As a practical illustration, it may be stated, that in working mixed steam, on board the Royal Mail Steam Packet Company's steamer 'Avon,' Mr. Drummond, the engineer, reported, that on one occasion, in the tropics, the temperature of the steam rose higher than usual, when he discovered, that the slides were being affected. Having the remedy at hand, he immediately turned on more saturated steam, since which he has experienced no further difficulty in running 150,000 miles.

For the purpose of testing the comparative efficiency of the three kinds of steam, the 'Avon' was worked; first, with ordinary steam; secondly, with the steam from three boilers superheated, the fourth boiler supplying plain steam; thirdly, with the steam mixed in proper proportions; the pressure on the boiler being, in each case, the same. The result was, that the plain steam gave 1,070 I.H.P.; that when three-fourths were superheated and one-quarter plain, it gave 1,076 I.H.P; and that when the area superheated, was 61, and that of the plain steam, 69, the result was 1,200 I.H.P.

The experiments which have been conducted by order of the Lords of the Admiralty, extending over twenty voyages, have shown, by the reports of the engineers who were appointed to conduct them, an average economy of 32 per cent. With a proper application of this system, an economy of from 30 to 50 per cent. can be realised, or a steamer will perform a voyage one-third further, at the same rate of speed, with the same weight of fuel. The Lords of the Admiralty are so well satisfied of the value of the system, that its application is being extended, and H.M.S. 'Rhadamanthus,' is to be immediately fitted with it. A plan has been submitted and approved, by which either kind of steam can be employed.

The mixed steam has been employed by Mr. Hobbs, (Assoc. Inst. C.E.,) in the high-pressure boiler and engine propelling his machinery. The application, in this case, simply consists of a pipe, 12 inches in diameter, convoluted in the flues of a Cornish boiler. Mr. Hobbs reports an economy of 33 per cent. in fuel, and in water. It has also been applied, by Mr. Dorman, to an engine which did not produce the required power. As there was no available space for the superheating apparatus, a separate furnace was placed near the engine. This resulted in an increase of power of 30 per cent., as was shown by indicator cards taken before and after the application. Combined steam has been applied to all the steamers of the Collins line. As there was not sufficient space in the up-take for the superheating apparatus, separate furnaces were employed. The effective economy, taking into consideration the increased speed of two revolutions of the wheels per minute, amounted to upwards of 30 per cent. Mr. Turner, Consulting Engineer to the Spanish and Portuguese line of steamers, made a series of experiments, on board the steamer 'Gibraltar,' with plain, superheated, and combined steam. The steam simply superheated, at a pressure on the boiler of 10 lbs., gave 222 I.H.P.; ordinary steam, at a pressure of 14 lbs., gave 307 I.H.P.; while combined steam, at a pressure of 15 lbs., produced 376 I.H.P. The combined-steam card was taken fifteen minutes after the ordinary-steam card, without

any alteration of the fires. The discrepancy between the pressures on the boiler, and those shown by the indicator cards, is readily accounted for. In employing ordinary steam, the pressure in the boiler can never be maintained in the cylinder; whilst, with the use of mixed steam, the pressure in the boiler is not only fully maintained, but it is frequently exceeded. It may be remarked, that the steam in the 'Gibraltar' was partially superheated, before the application of the mixed steam.

If it is asked, why superheated steam at the same temperature, will not produce the same increase of power, or exhibit the same economy as mixed steam, it may be replied, that when steam is merely superheated, or dried, it is converted into steam gas. It partakes, consequently, of the nature of gas; it is a bad conductor of heat, and it gives out, with difficulty, the heat necessary to transform it into mechanical power. On the other hand, mixed steam participates, at the same time, in the qualities of steam proper and of superheated steam, being a pure, highly-rarefied vapour, which readily parts with its heat, and thus produces greater mechanical power. In the experiments which have been made with the mixed steam, the difference of temperature between entering and leaving the cylinder was always greater than when ordinary, or superheated, steam alone was used. As more heat was utilised, greater mechanical power was the result.

Experience has proved, that the application of combined steam presents the following advantages:—An economy of fuel of from 30 to 50 per cent.;—a diminution of about one-third in the quantity of water necessary for feeding the boilers, and consequently, of the deposits which corrode them;—the employment of smaller boilers to obtain the same power;—the facility of maintaining the desired pressure, or of increasing, at will, the motive power, in cases of emergency;—a steamer will make a voyage one-third further with the same weight of coal, or one-third of the space now occupied by coal may be used for freight;—there is less risk of explosion, as there is no necessity for a high pressure in the boiler;—boilers will last one-third longer;—a better vacuum is obtained;—and finally, one-third less injection water is required.

It may be proper to state, that this Paper presents no crude theory of an untested principle; but the faithful description of a plain and simple application of the combination of vapour and gas, by which, not only the long-known increased power of the latter, at high temperatures, is effectually controlled, but the fact, highly interesting to science, is established, that the power is greatly increased. At the temperature which is necessary to develop the full power, steam gas becomes so entirely dry, that for want of lubrication, it is destructive to the rubbing parts

of the machinery; whilst combined steam develops increased power, which can be utilised to its maximum extent, with entire safety, as has been most satisfactorily demonstrated, by the test of long experience.

The Paper is illustrated by diagrams, showing the results of the different experiments.

[The Honourable JOHN WETHERED

The Honourable JOHN WETHERED said, that since the Paper was written, he had learned, that in one instance, the coil of pipes in the separate furnace built on the plan of Mr. Perkins, had become oxidised and destroyed, where there was actual contact with the fire, after the apparatus had been in operation only a few months. It had been said, that iron pipes could be thus employed without injury, but he had never met with any such instance in his own experience; when thus exposed, they answered very well for hot water, but not for steam.

He had requested Mr. Dinnen, who was appointed by the Admiralty to superintend the experiments in H.M.S. 'Dee,' to take indicator cards, with superheated and combined steam at the same pressure, taking care that the supply valves should be each of equal area. The cards showed, that a better vacuum was obtained, and that the expansion was much greater, when using combined steam. During the voyage of the 'Dee' to Plymouth, when those cards were taken, the consumption of fuel, by using combined steam, was 2·57 lbs. per I.H.P. per hour, whilst the average consumption in thirteen trials with plain steam, was 5·53 lbs. per I.H.P. per hour. The engines, it should be stated, were built, twenty-seven years ago, by Messrs. Maudslay and Co.

In reply to a remark by the President,—that the boilers of the 'Dee' might have been new, and that the superheated steam appeared to have been used at a pressure of 8 lbs., whilst the pressure of the combined steam was higher,—Mr. Wethered said, the object was to take the cards at exactly the same pressure, but as soon as the superheated steam was turned off, the pressure invariably rose half a lb.

In reply to other questions from Members, he stated, that he proposed to mix the steam as near to the cylinder as possible, and in the case mentioned, this was done close to the steam chest; and that 2 superficial feet of heating surface for each nominal H.P., would give about 500° of temperature.

Mr. LONGRIDGE had not lately paid much attention to superheated steam, but having used it, about fifteen years ago, he found the economy to be much nearer 10 than 30 per cent. In one, or two instances, he was obliged to take the steam through a long range of pipes, and in spite of all the protection he could give them, there was a considerable amount of condensation, although the vertical pipe of cast iron was surrounded by flame, and a special furnace was built for the purpose. If the engine was a moderately good one, the advantage of heating the steam in the cylinder, would not amount to 30 per cent. By passing steam into the cylinder and using it expansively, a portion of the steam was, no doubt, condensed; and if a sufficient charge of heat could be previously given to the steam, to prevent that condensation,

a nearer approach might be made to the true theoretical result of expansion, and a better vacuum obtained. But even if the best system of superheating was applied to the best expansive engine, and condensation was altogether prevented, he doubted whether the benefit arising from superheating, would amount to more than about 15 per cent. Great importance had been attached to the effect of ordinary superheated steam upon the valves and the packing; now if this extra-heated steam was introduced, along with the other steam, into the steam chest, so as to give it that charge of heat necessary to prevent condensation, he could not see what difference there was between that system and heating the whole of the steam exactly to that point. He had also directed his attention to the amount of heat that could be imparted, by superheating the up-take. He did not know what proportion of the steam it was intended to pass through the apparatus employed for this purpose, but in any case, the amount of heat imparted would be small. Some experiments, in which he had formerly been engaged, relative to the consumption of smoke, bore upon this point, as they, eventually, took the form of ascertaining the evaporative power of different fuels. For this purpose he employed a good marine boiler, of the ordinary type, and he found, that in the up-take before the chimney, the temperature of the gases was, generally, when burning a moderate quantity of fuel, about 600°; and that when burning a large quantity of fuel, say 30 lbs. per square foot of fire grate per hour, with the ordinary draught, the temperature rose to 700° and 750°. The general temperature of the gases, however, was 600°. He then took off the chimney and put up a vertical tubular boiler, through which all the gases passed, the tubes being 3 inches in diameter. These tubes contained, in the aggregate, 320 square feet of exposed surface, or nearly equal to half the whole surface of the boiler, which was 740 square feet. The water entered the heater at a temperature of about 60°, and as was expected, reduced the temperature of the chimney, but only to a small extent, for the gases which entered the heater at 600°, came out at 550°; so that only 50° of heat were taken off by the 320 feet of surface. He had ascertained the temperature of the gases before they passed into the tubes, by Daniell's pyrometer, and he found, that with brisk combustion, it was about 3,000°. The tube surface reduced this temperature from 3,000° to 600°, and thus four-fifths of the heat of the gases were abstracted, whilst by the 320 square feet of the heater, only one-twelfth of the remaining fifth was abstracted, or one-sixtieth of the whole, showing the small effect of the heating surface in the up-take.

Mr. A. C. Hobbs stated, that he had a small engine, with a Cornish boiler, which formerly required 36 cwt. of coal, per week. By the introduction of a pipe 40 feet in length, into the side flue,

the temperature in the cylinder was raised from 270° to 330°, or 340°, and the consumption of coal was reduced from 36 cwt. to 28 cwt. per week. With another set of pipes in the other side of the boiler, the temperature rose to 420°, but at that temperature, a peculiar action took place in the cylinder which induced its reduction to 360°, by the introduction of plain steam; and at that point, the consumption of fuel was as low as 24 cwt. per week. Formerly, the tank containing the feed water, ran short; but now, one-third of the water was unconsumed daily. The same man had attended to the firing of the furnace, before and after, the change. The economy thus effected, without any alteration of the engine, or of the boiler, was one-third, and it had continued in the same proportion, for the last eight, or nine months. He had since tried the experiment of discontinuing the superheated steam for some days, when the consumption of coal and water invariably rose to the original amount.

Mr. HUMPHRYS said, that to the Author of the Paper was due all the credit of having taught the use of superheated steam. His own attention was first drawn to the subject, by the experiments of the Admiralty; and from what he then observed, and from his subsequent experiments, he did not think, that the mixing of steam could afford any advantage superior to that of superheating the whole. He was employed by the Peninsular and Oriental Company, to apply superheated steam to those of their vessels of which he had supplied the engines. The 'Ceylon,' which ran between Southampton and Alexandria, was the first; its engines had cylinders 72 inches in diameter, with a stroke of 3 feet, and making from fifty to sixty strokes per minute. At that time, she had run a distance of about 42,000 miles, having performed seven passages with ordinary steam; and the consumption of fuel, out and home, was 1,500 tons per voyage. The superheating apparatus was applied, and it increased the temperature of the steam, rather more than 100°. The surface in that apparatus was about 1 foot per I.H.P., the engines working to three, or four times their nominal power. She had now completed five voyages, or a distance of 30,000 miles, and the average consumption of coals had been, 1,100 tons per voyage. The cylinders, slide valves, and all the parts of the engines, were in better condition now, than when the apparatus was first applied. In the 'Alhambra,' the consumption of fuel, previous to superheating, was 19 cwt. per hour; it was now reduced to 13 cwt. per hour, with the same, or rather an increase of speed. The economy effected in the 'Nepaul,' was most remarkable; she formerly consumed 36 tons per day, whereas since superheating had been used, the consumption had declined to only about 17 tons per day. The whole of the steam was superheated, and the temperature was in-

creased about 100° over that due to the pressure. In all cases, he allowed one superficial foot of surface in the superheater for every indicated H.P.

In reply to a question from Mr. Wethered, Mr. Humphrys said, it was difficult to ascertain the consumption per I.H.P. The engines of these vessels were, generally, worked at about three times the nominal power; the "Nepaul," of 200 H.P., was working up to 700 H.P.

Mr. Patridge acknowledged, that although experiments in superheating steam had been previously tried, great praise was due to the Author, for having recalled public attention to the advantages to be derived from its employment. He observed, that the indicator card representing the superheated steam alone, was produced by steam throttled by the small size of the steam pipes; whereas that representing mixed steam, was produced without any such obstruction. The engines from which those cards were taken were two in number, each of 100 H.P. The two superheated steam pipes conveying the steam to the cylinder, were not in connection. When the arrangement of the steam pipes was first made, it was not intended to work both engines with superheated steam, at the same time, but each engine with plain and with superheated steam, alternately, and the minimum diameter of the pipes which conveyed the superheated steam, was only 9 inches. It was afterwards decided to make trials with superheated steam alone, in both engines at the same time, and then the two superheated steam pipes were connected, and larger stopcocks were fitted. The cards taken since that alteration, had been quite equal to that representing the mixed steam, and in his opinion, the comparative fulness of the steam line of that card was due to the fact, that the large ordinary steam pipe was in connection with the engines, in addition to the superheated pipe, and not from the fact of the steam being mixed. Taking a cubic foot of steam at a pressure of 10 lbs., raised to a temperature of 300° by a direct process of superheating, then taking superheated steam at 500° mixed with ordinary steam so as to bring the mixture to 300°, his impression was, that the water in a cubic foot of either steam, at the same pressure, would be equal; and that, therefore, their lubricating qualities would be similar. Great economy, no doubt, resulted from the use of superheated steam; he believed that, in the best boilers, if the steam was raised 100° beyond the temperature due to its pressure, the saving would be equal to 15 per cent. But in one vessel, with an indifferent construction of boiler, when comparative trials were made with plain and superheated steam, the result was an economy of 34 per cent., in favour of the employment of the latter. This was partly due, in his opinion, to the construction of the boiler, and to the application of the apparatus having

increased the amount of steam room. He did not believe, that the use of superheated steam was detrimental to the engine; the 'Dee' was a proof of this. In that vessel, the temperature of the superheated steam at the boiler was about 380°, the length of the main steam-pipe being between 30 feet and 40 feet. The difference of temperature between the steam at the boiler, and at the end of the steam pipe next the cylinder, was about 20°. There was a considerable reduction in the temperature of the steam in the slide jacket, before it entered the cylinder, so that, although the steam at the boiler was 380°, it was reduced about 70° in the slide jacket, prior to its entering the cylinder, bringing it down to 310°, and sometimes, to 300°. The 'Dee,' he might add, had been running with superheated steam for more than two years, yet there was not the slightest appearance of any injury to the machinery; nor had there been any deterioration, or difficulty in the packing.

In reply to a question from the President, Mr. Patridge said, that in all cases, with ordinary steam, the temperature in the cylinder was much lower than that due to its initial pressure, but he had found it very difficult to ascertain the temperature of steam in the cylinder, owing to its rapid decrease throughout the stroke.

Mr. John Topham, having had opportunities of fitting superheating apparatus to vessels, would state the results. In one of the vessels belonging to the Intercolonial Royal Mail Company, the consumption of fuel was, formerly, 2,986 lbs. of coal per hour. The apparatus, consisting of a number of boxes of short tubes, fitted in front of the ordinary boiler tubes, and connected, by a wrought-iron cylinder placed in the funnel, with the boiler, through which the steam passed freely, was applied, and had the effect of immediately reducing the consumption to 1,900 lbs. per hour, with scarcely any variation during the passage of four, or five days, from London to Milford Haven. The temperature of the superheated steam was from 310°, to 340° and 350°. In the steam pipe, half way between the boilers and the cylinder, the average temperature was 330°. No injurious effects resulted from the use of superheated steam, nor was there, in the voyage of the same vessel from Milford Haven to the Cape of Good Hope, any trouble experienced with regard to the packing, which was of the ordinary kind, canvas and india rubber. The 'Airedale' was also supplied with the same apparatus, and the report of her performances was so favourable, that the Company determined to have their other vessels fitted in a similar manner. He would particularly call attention to the fact, that, within certain limits, the area of the heating surface in the superheating apparatus, should be as large as possible. In a new vessel recently fitted on this system, the area was only 45 superficial feet, scarcely more than half a square foot per nominal H.P.; that proportion of

heating surface was far too small, and would be of little use. In another case which had come under his notice, a wrought-iron cylinder was fitted into the lower part of the chimney and filled with seventy-eight, or eighty tubes, $4\frac{1}{4}$ inches in diameter and 7 feet in length. The area of heating surface was 800 feet, or 4 superficial feet per nominal H.P. He expected, that the consumption of fuel in that vessel would be much reduced The Author's system of combined steam was applied to the 'Gibraltar.' When the boilers were first fitted, the superheating system was partially adopted. Between the tops of the ordinary boilers was placed an ordinary cylinder boiler, with the addition of a tube to carry the heated air from the up-take through this boiler, which was connected with the others by steam pipes, into the chimney, so that before entering the funnel, the smoke and flame passed through the tube in the cylinder boiler, for a space of 14 feet, or 15 feet.

Mr. PARSON said, that the advantages of superheating had been sufficiently established, in an economical point of view, by the results already given; therefore, not being himself a professional Engineer, he would not have offered any remarks upon this subject, but for the observations which had been made upon the system of superheating by means of pipes placed directly over the fire,—a system in which he was much interested. That arrangement had been adopted in the 'Osprey,' one of the boats of the Watermen's Company, which had been running uninterruptedly for ten months. In no case had the pipes lasted less than five months, and whenever they had given way, it was owing to their not having been properly welded; no injury had ever occurred, when the weld was double lapped. The saving by this arrangement was greater than that effected in the 'Dee.' The certificate of the manager of the Waterman's Company stated, that it amounted to between 30 and 40 per cent., and it had, therefore, been resolved, that the whole of that Company's vessels, thirteen in number, should be fitted with the apparatus, for the approaching summer. The engine had not sustained the least injury, for according to the statements of the Company's engineer, the cylinders in the 'Osprey' were as perfect as when common steam was used. The Author of the Paper had visited the 'Osprey' on several occasions, and had expressed his admiration of the apparatus employed.

Mr. HUMPHRYS said, that a good example of what might be accomplished by superheated steam, was afforded by an engine in use at the works with which he was connected. The piston travelled at the rate of 530 feet per minute, and the consumption of coal did not amount to 2 lbs. per I.H.P. per hour. At present, 15 lbs. of water per H.P. per hour, were converted into steam; whereas before superheating was applied, the quantity was 17 lbs.

per H.P. per hour. In this instance, all the steam passages were surrounded with steam cases.

In answer to a question by Mr. Greaves, Mr. Humphrys said, that in the case of the Peninsular and Oriental Company's vessels, previously referred to, the cylinders were not jacketed.

Mr. W. Beardmore said, that by the use of superheating apparatus, he had effected a saving of from 15 to 25 per cent. in the consumption of fuel. In some instances, where the boilers did not freely generate steam, the economy was apparently slight, but in boilers affording a good supply of steam, it was as much as 23 per cent. In one of the boats belonging to the General Steam Navigation Company, travelling between the Thames and Scotland, an average of twelve voyages, previous to superheating, showed a consumption of 126 tons of fuel per voyage; it was now reduced to about 90 tons per voyage. That was the largest amount of economy he had observed. The temperature of the up-take was from 650° to 680°. After superheating, it was not reduced more than 50°, but the temperature of the steam was increased 100°.

Mr. Howard had expected, that greater prominence would have been given in the discussion, to the rationale of superheating steam. He had practically experimented upon it on a large scale, about thirty years since, having, long ago, perceived the scientific grounds for its adoption, and wherein its chief advantages consisted. Although the Author was entitled to all the credit which had been given him, for having resuscitated the question, and having brought it prominently before the Engineers of this country, Mr. Howard doubted, whether he had rightly understood the theory of its use. There was no advantage in mixing steam. Two quantities of water at different temperatures, might be mixed together and be called combined water, with as much propriety as to give the name of combined steam to two quantities of steam, at various degrees of heat. It was not strictly a combination, but a mixture. Whether steam were superheated by external appliances, or by adding surcharged steam, it made no difference. There could be no doubt of the advantages of the use of superheated steam, but the cause must be sought for in another direction. He had made experiments on the four low-pressure engines at his own works, the King and Queen Ironworks, Rotherhithe, further confirmatory of his views, that the gain did not arise from any physical law, but from the prevention of loss in the use of dense steam. When the steam entered the cylinder, if there was but one degree of heat less in the cylinder, water must be formed, the resultant effect of which had not been appreciated; not even, he believed, by Watt himself, for the pressure in the cylinder being maintained from the boiler, his pressure gauge, or indicator did not show the loss.

When the vacuum stroke was made, the deposited water being relieved of the pressure due to its temperature, rapidly passed off as rarefied vapour, cooling the interior of the cylinder. On the steam entering to make the return stroke, it brought the cylinder up to a temperature due to its pressure, for otherwise, it could not act to its full pressure; and the stroke was made at that loss, by the deposit of water over the whole interior surface of the cylinder and its adjuncts. When the condenser again came into action, the same thing recurred, and so on continually. He had applied the pressure indicator simultaneously with thermometers, and he found, that the loss of temperature in the cylinder, without working expansively, with an average pressure of 8 lbs. in the boiler, approached 20°, which indicated a loss of steam of between one-third and one-fourth. This injurious effect must always occur by using dense steam, whereas, by using superheated steam, there was no deposit of water, and the action was analogous to that of a permanent gas, but with the advantage of easy and complete condensation. This, he believed, to be the rationale and the cause of its superiority. It was also stated, that by mixing superheated steam with dense steam, the power was increased, by vaporising the vesicular water which came from the boiler. Now supposing, for example, (for the same proportion would hold good in all cases,) that in a cubic foot of steam, at the atmospheric pressure, being 1 cubic inch of water with 1,000° of latent heat, there was half a cubic inch of free, or vesicular water, in suspension, and that all the latter was to be vaporised by the application, or admixture of superheated steam; then there must be added the necessary proportion of 500° for the latent heat of conversion, giving an increase in volume of half a cubic foot. A cubic foot of superheated steam, surcharged by 500°, or more strictly, 460°, would become double its original volume. Now the 500° had been taken from the superheated steam, and thus its own volume was reduced one-half. With all deference to the Author, he believed his theory of the combination of the two kinds of steam to be a fallacy, and he could not accept it as explanatory of the advantages unquestionably attendant upon the use of superheated steam; nor was it necessary to raise the temperature very high, about 100°, or indeed less, above the normal temperature, being ample. There was another gain in superheating. When the vacuum stroke was made, since the cylinder was perfectly dry, the exhaustion of the whole steam was performed in a moment; but with dense steam, the cylinder being wet, the deposited water had to be vaporised and condensed, and thus damaging the vacuum. As this action did not occur with superheated steam, some increase of mechanical effect was produced. The condensing appliances were also relieved, by so much as was gained in the cylinder.

He had used such steam expansively, for which it was well adapted.

Mr. PATRIDGE said, his experience was confirmatory of the fact, that by the use of superheated steam to obtain the same amount of power as by ordinary steam, the feed water was reduced about one-third, and about one-fourth less water was required for condensation.

Mr. CHARLES MAY observed, that in the explanation which had been given of superheating, there was one element which had been omitted. When steam was expanded, a large quantity of the heat became latent; the full effect, consequently, was not obtained from expanding ordinary steam, because, as it expanded in the cylinder, it cooled, and there was not sufficient caloric to keep up the specific heat during the stroke. He thought the practical limit of the use of superheated steam would be found, in giving it such an additional amount of caloric, as would permit of its remaining dry steam, to the end of its required expansion.

Mr. HOWARD observed, that while by superheating steam, the loss arising from the use of dense steam was prevented, another advantage was derived by the utilisation of the waste heat in the up-take. The bulk of the steam being doubled for every 460° of temperature, about one-fifth, consequently, was added to it by the 100° gained in the up-take, and that was sufficient to support the elasticity of the steam, from one end of the stroke to the other. In his own experience he had found little advantage to have resulted from the use of steam jackets, and experiments showed, that the heat was not transmitted with sufficient rapidity through the jackets, to have any material influence, at least, when the piston was reciprocating very rapidly.

Mr. DINNEN,—through the Secretary,—would call the attention of the Meeting to the views entertained by many professional men, respecting the condition of common steam, before superheating. The Paper spoke of 'vesicular water' being converted into steam; others had spoken of 'wet steam.' Now this was altogether opposed to his own experience and observation; he had never found wet steam, unless the water of generation was more, or less charged with adventitious matters and caused the boiler to prime; then the water was manifestly vesicular, for the vesicles of steam were seen in active motion in the glasses of the water gauges. It was true, that water, not vesicular, would pass over with the steam, if too little steam room was afforded; but that was not priming, properly so called. The best practical proof of steam from a boiler being plain, or common steam, was, that he had travelled over thousands of miles at sea, without drinking any other water than that produced in the jacket of the steam engine; had it been vesicular it must, he thought, have been salt. In fact, the law, that

pressures and densities were invariable, and the formulæ founded on experiments thereon, must fall to the ground, if the Author's views were correct. Steam, in contact with its water, must, therefore, be taken as saturated, in considering the question of superheating alone, or of mixing according to the principle of the Author. He had made several voyages in H.M.S. 'Dee,' of 200 H.P., with the view of testing the comparative advantages of both systems. He would first give the results of two trials with common steam, against steam simply superheated. Equal pressures of 3½ lbs. in the boilers, gave equal H.P. and equal amounts of injection, but with an economy of 23·8 per cent. in favour of superheating; each boiler and engine being alternately used on the respective systems, while still working on the same shaft, so that external influences operated equally on both. It was worthy of remark, that the plain steam exhibited, within 1°, the same temperature at the boiler, as it did after passing through the jacket to the slide casing; while the superheated steam fell 20° on its passage from the boiler to the cylinder, a distance of 37½ feet. It fell 82° after entering the jacket, and it lost 26° more, after entering the cylinder; while the plain steam, after making its entire circuit from the boiler into the cylinder, lost only 23°. The superheated steam left the boiler at 382°, and it retained 251° in the cylinder; while the plain steam was 220° at the boiler, and 197° in the cylinder. The most curious and instructive feature of this experiment was, that there was no water formed in the jacket, when superheated steam was used; but a considerable quantity was deposited, as usual, from the plain steam. Another experiment with superheated and plain steam, when each system was allowed full play, gave the following results. Steam, when superheated, was easily kept to a pressure of 7 lbs. in the boiler, but a pressure of only 4 lbs. was maintained, when common steam was used; with superheated steam, 245 H.P. was obtained, and with plain steam, only 213 H.P.; and there was, moreover, an economy of coal equal to 20 per cent. in favour of superheating.

The Author's system, when manipulated by himself in the 'Dee,' so as to obtain, as nearly as possible, equal temperatures in the cylinders, was about as economical as the superheated steam, when the whole was passed through the superheater. The H.P., on both systems, was about the same, when each engine was worked on a separate principle: but when the engines were worked in pairs, on the respective systems, Mr. Wethered was enabled to develop more power, on account of the superheating pipes being too small to pass all the steam that the boilers were capable of developing. The fact of the superheated steam having lost 20° only, by radiation from the long steam pipe, while at the jacket it lost 82°, pointed directly to the seat of loss of both power and economy. The necessarily low mean temperature of the masses of

the cylinders, pistons, &c., and the large amount of jacket water yielded, when plain steam was used, without any tangible difference in temperature between the boiler and the jacket, must be conclusive, that much power was sacrificed, before the steam entered the cylinder. It should be remarked, that a certain quantity of jacket water was always obtained, when combined steam was used, but none was ever obtained from the superheated steam, until it was cut off by the expansion gear before half-stroke, when jacket water manifested itself, and the economy of fuel began to fall off. This, as he had remarked on a former occasion,[1] might be considered the dew point; and superheating, to be fully effectual, should, in his opinion, be carried at least as far as in the 'Dee,' where the best result at full power, was 2·6 lbs. of Welsh coal per indicated H.P., when both engines were working on the same system, at the same time. If superheating was carried farther than was necessary to prevent condensation in the jacket, and therefore, in the cylinder, the effect was likely to be injurious to the working parts, and to carbonise the packings and lubricating substances. Neither of these results had occurred, during his voyages in the 'Dee.' When an excess of heat, beyond the point alluded to, was experienced in superheating, the remedy must be looked for in the boiler, unless there was a power of reducing the temperature.

The amount of heat suddenly lost at the jacket,—from 80° to 90° in the 'Dee,'—pointed to that portion of the apparatus as the one through which means should be found, for maintaining a suitable temperature in the cylinder. He thought, therefore, that the whole of the steam passing into the cylinders, should be made to pass through the jacket, if the construction would admit of it, rather than that the jacket should be fed by small pipes.

Subsequent voyages in H.M.S. 'Rhadamanthus,' fitted with engines of about the same power and construction as those in the 'Dee,' furnished results entirely confirmatory of those obtained in the latter vessel.

Mr. Rennie had witnessed the experiments of the Author at Paris, and he fully believed, that the saving effected by the Author's system was from 24 to 30 per cent., but he had not actually verified the fact. The experiments he had himself conducted, merely carried out the ideas of others. The firm with which he was connected, had been early in the field, and had fitted eighteen sets of apparatus, some upon the plan of Mr. Patridge with tubes, and some on Mr. Lamb's principle with flues, from both of which good results were obtained. With the first, he considered the saving to be about 25 per cent., and with the other about 30 per cent. He had supplied the superheating

[1] *Vide* Minutes of Proceedings Inst. C.E. vol. xviii. p. 277.

apparatus for the 'Pera,' which now consumed 380 tons less than formerly, or about 1,200 tons of coal per voyage. He was desirous of knowing why the Author preferred combined steam, and what advantage he found in using several small boilers, instead of one large boiler.

Mr. C. W. SIEMENS had, for nearly the last fifteen years, occupied himself with this question. When he first turned his attention to the subject, he endeavoured to ascertain the advantage of superheating steam, and he made some rather elaborate experiments to determine the rate of expansion. He found, that Gay-Lussac's law of an uniform rate of expansion of elastic fluids by heat, was not applicable, but that steam, near its point of saturation, expanded in a greater ratio than afterwards. A curve representing the rate of expansion was rounded at the beginning, but gradually approached a straight line; it was, in fact, a hyperbola, the asymptote of which ran parallel to a line representing the uniform progression of expansion of air. So that at a temperature considerably removed from the boiling point, air and steam expanded, practically, at the same rate; whereas at first, steam expanded four times, or five times more than air, for the same increase of temperature. He also found, that steam near its point of saturation, possessed great capacity for heat; and therefore, by simply superheating steam, no great economy could be produced. The results of recent practice showed, however, in many instances, a very large saving, which might be ascribed to a secondary cause. Steam, in expanding behind a working piston, lost a portion of its heat, which was converted into mechanical effect. This heat was entirely lost, and a portion of the steam must condense, or form water. This water re-evaporated when the pressure had become reduced by expansion, and cooled the sides of the cylinder, thereby producing condensation in the fresh steam from the boiler; and thus an action was established on the sides of the cylinder, (resembling that of a sponge, which, under the influence of an alternating pressure, absorbed and emitted water,) by which a certain amount of steam passed, at each stroke, through the cylinder, without exerting its elastic force upon the piston. To prevent this action, it was necessary to sufficiently increase the temperature of the steam, that it might be expanded through the stroke, without condensation. According to the present well-established law, expressing mechanical force by the quantity of heat, he found, that an increase of temperature of 100° Fahrenheit, would suffice to prevent condensation in an ordinary expansive engine. Increasing the heat beyond that point would not be accompanied with any marked economy, and would engender many difficulties; lubrication would become difficult, and friction would be produced. Great stress had been laid upon the

peculiar properties of mixed steam, and the advantages which it possessed over superheated steam, but he had never seen any remarkable results from its use. In an engine which he designed, he virtually used the two steams together, inasmuch as, at each stroke, he added to a volume of superheated steam, a certain proportion of saturated steam; but he never observed any spontaneous increase in the bulk. There was, however, one advantage in the Author's system,—by mixing ordinary saturated steam with superheated steam, he had the means of regulating the temperature. If, then, a compensating rod was introduced into the steam pipe, so as to limit the admission of steam in proportion to the temperature, beneficial results might be obtained. He was convinced, however, that in simply superheating steam, the ultimate degree of economy would not be reached. The chief advantage of superheating was to prevent condensation in the working cylinder, whereas Mr. Siemens's object had been, and still was, to prevent the loss of the latent heat of the steam, by means of the regenerative system. Although he had advanced but slowly, owing to the difficulties and expense attending experiments of this description, he had two engines at work, which gave him every confidence of ultimate and complete success.

Mr. LAVINGTON E. FLETCHER remarked, that the idea of superheating steam was not new. Fifteen years ago, there were two locomotive engines on the Great Western Railway, which were each fitted with a superheating apparatus, consisting of a tubular steam chest placed in the smoke box, the hot air passing through the tubes; but the system was not favourably received. Messrs. Hawthorn, of Newcastle, made several locomotive engines, with return tubes for superheating the steam, but they did not come into general use. Others tried superheated steam, and condemned it. In America, Mr. Frost brought out a system of superheating to a high temperature, but the engine was so much injured by friction, that the experiment was abandoned. These repeated failures had caused the use of superheated steam to be much neglected, until it was successfully applied by the Author, at moderate temperatures, to marine engines. Mr. Fletcher differed from the Author as to the merits of combined steam. He had been shown the results of most elaborate experiments made by competent Engineers in France and America, who reported, that they had certainly met with anomalous effects for which they were not prepared, and that combined steam appeared to present superior advantages to ordinary superheated steam. Until he had had the opportunity of verifying these results, he could not, however, pronounce in favour of combined steam, since its stated action was altogether of so novel and anomalous a character. He was about to apply it in one, or two cases, and if he found any

advantage from its use, he would communicate the result to the Institution.

As to the rationale of the economy resulting from the use of superheated steam, some views had been advanced with which he could not agree. It was said, that the economy was produced by the evaporation of the vesicular water which passed over with the steam, when the steam was not superheated. But the gain arising from this could not be large, for even if one-fourth part,—and that would be an extreme proportion,—of the water supposed to be evaporated in the boiler, passed over unevaporated, in a vesicular state, the heat carried over by that amount of water, and consequently wasted, would be only one twenty-fourth part of the whole heat of evaporation; thus the gain by the prevention of this waste would not be more than about 4 per cent., and was inadequate to explain the full amount actually experienced, which was 25 per cent. By others, the economy was attributed to the utilisation of waste heat in the funnel. But since the steam was only raised about 120°, by superheating, it followed, taking the specific heat of steam into account, that the heat absorbed in superheating to that point, would not amount to more than about 3 per cent. of the whole quantity; this cause, therefore, was also insufficient to account for the result produced. The principal source of gain in the use of superheated steam consisted, in his opinion, in the prevention of condensation in the cylinders, which gave rise, as he had already observed at the discussion, in 1859, on the combined-vapour engine,[1] to an alternate action of re-evaporation and condensation, destructive of all economy. He so entirely agreed with the remarks of Mr. Howard upon this subject, that he thought it unnecessary to offer any further explanation. In addition to the direct economy produced in the expenditure of steam in the cylinder, there would also result an indirect advantage from the relief afforded to the boiler, which would enable it to perform its duty more economically. He concluded, therefore, that whilst the economy produced by superheating steam mainly arose from working with dry steam, and thus preventing condensation in the cylinders, all the other causes, to which should be added the increased volume of the steam due to superheating, contributed to the advantageous result. He thought, that if the use of Watt's steam jacket had been continued to the present time, it would have saved the steam marine a large sum. The action of the steam jacket had, evidently, been misunderstood, and its advantages unappreciated. Mr. John Bourne, in his "Catechism of the Steam Engine,"[2] said:—"The cause of this effect is not of very

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xviii., p. 282.
[2] *Vide* "A Catechism of the Steam Engine, &c." By John Bourne. 8vo. 4th edition. London, 1856. Page 288.

easy perception, for the jacket exposes a larger radiating surface for the escape of the heat, than the cylinders; nevertheless, the fact has been established beyond doubt, by repeated trials, that engines provided with a jacket are more economical than engines without one." Tredgold described the steam jacket as a useless incumbrance to the engine, which had better be dispensed with.

Mr. J. James mentioned, that many years ago, Captain Douglas had used superheated steam in India. He was about to return to England, and would willingly furnish all the information he possessed. Mr. James had been engaged in experiments for him on the subject, but was not, at present, in a position to give an account of them.

Mr. Greaves observed, that there was a general law which supposed the existence of a relation between temperature and pressure, in all conditions of steam. But in pursuing the variations of this relation, it became necessary to separate fluidity from elasticity, and to distinguish between the mere enlargement of the cylinder space, filled with steam of initial density, or a similar enlargement accompanied by a density diminished simply by spontaneous expansion, and carrying a diminished load; and an enlargement arising from a strong initial impulse, as in the Cornish engine, and from a continued impulse, as in rotative engines, whether for locomotive, or fly-wheel motion. To counteract the loss of force, or power due to condensation, or external radiation of heat, superheating, clothing and jacketing were, undoubtedly, most useful. Any process by which steam could be generated and maintained at a temperature sufficiently high, that it should never condense in the cylinder, would be attended with economy; but beyond this, he was not of opinion, that there would be any advantage from superheating, when engines were not worked expansively. When an engine was worked on the Cornish system, and a load, say of 12 lbs. per inch, was started into motion, by a pressure of 33 lbs., diminishing, after the steam was cut off, to 6 lbs., or 7 lbs., the motion being altogether irregular,—or in a rotative engine, or in an engine with a fly-wheel, where the same irregularity of pressure took place, yet with a regular motion,—whenever, in short, the motion was not produced by a force always maintained equal to the load, then the necessity for superheating, or clothing and jacketing became urgent, and to neglect such provisions was most prejudicial. In these cases, the expansion was not continually spontaneous, and therefore, to the loss of heat by radiation, was to be added a further loss due to the expansion produced by the result of a past effort. This, for the sake of economy, should be obviated, by maintaining from another source, the highest possible temperature the steam itself could carry. Al-

though fully impressed with the advantage and economy of steam jackets, where they could be conveniently fitted, to engines working expansively, yet he had no doubt, that equal benefit would be obtained by superheating, where the jackets could not be applied. But in engines not worked expansively, the same advantages might be obtained by a proper system of clothing.

Mr. Hobbs observed, that his engine was not worked expansively, yet the economy was about 33 per cent., simply from superheating.

Mr. E. A. Cowper differed from the opinion, that if an engine was worked with full steam throughout the stroke, a steam jacket would not be of any advantage. If, indeed, the cylinder was never opened to the condenser, or to the atmosphere, he agreed, that the water which was condensed would then remain in the cylinder; but whenever the eduction valve was opened and the steam was let out of the cylinder, evaporation took place, and the effect on the cylinder was the same as in an expansive engine; the only difference being, that in one case, the expansion took place quickly and after the piston had made its stroke, whilst in the other case, the expansion took place more slowly, and during the time that the piston was making its stroke. He granted, that there would be as much radiation from the steam jacket as from the cylinder, but the advantage of steam jackets was far greater than the mere question of radiation indicated. If the cylinder was kept hot by a steam jacket, no steam would condense in the cylinder when the steam entered it, and, therefore, no water would have to be evaporated when the steam passed out; thus all the steam passing through the cylinder would be utilised, instead of a portion only, as was the case in all engines without steam jackets. He had taken numbers of diagrams, showing the extent of the loss which occurred with different amounts of expansion, when no steam jacket was used, and he had mentioned the results last Session.[1]

In one case, when the steam was cut off at one-eleventh of the stroke, the loss was 44 per cent. Immediately after the steam was cut off, the fall in the curve was very rapid, owing to condensation; instead of falling below the true expansion curve at the end of the stroke, it fell much slower, and towards the end of the stroke, it had almost a tendency to become horizontal, from the re-evaporation of the water. He thought, therefore, that steam jackets were very valuable in any engine, whether working with full steam, or expansively, and he rejoiced to hear, that Government had given instructions, that several marine engines, which they had lately ordered, should be supplied with them.

So far back as 1834, or 1835, when he was a pupil, he wit-

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xviii., p. 284.

nessed some experiments with Ericsson's engine, in which superheating was carried to a higher degree than in any of the cases now alluded to. The results showed, that an engine of 24 H.P. could be worked with a very small fire, but there were, at that time, some practical difficulties which prevented the general adoption of the system. In 1843, an engine was worked at Coventry, with mixed air and steam; the air was pumped at a high temperature through pipes and mixed with common steam, and considerable effect was produced, though, probably, without any economy.

The first advantage of superheating, was to evaporate all the water contained in the steam; the next was to prevent the loss by condensation in the steam pipe, and the cylinder, thus saving the cost of a steam jacket; the third was to increase the bulk of the steam; the fourth was, that more of the steam was condensed into water, from a portion of the heat being converted into power, by expansion; and lastly, superheated steam condensed more readily, from its having no water in it, requiring to be cooled down, before a good vacuum could be obtained. He had applied superheating to a pair of engines of 25 H.P., but he was unable to state the exact saving in fuel. He had no doubt, however, that in engines with bad boilers, it would be, in many cases, as much as 30 per cent.; but in engines, where the boiler was really good and generated dry steam, and the cylinder was protected by a steam jacket, so large a saving must not be expected. He hoped, that superheating would, eventually, be carried much further, and in such a manner, that the work would mainly be done by the expansion of steam, without the loss of so much latent heat as at present. The consumption of fuel had been less in Mr. Siemens's engine, in which common and superheated steam were combined, or mixed, than in any other, though not owing to such mixture; and it was satisfactory to find, that the result of the Author's experiments agreed so nearly with those made by others, as to the temperature at which ordinary cylinders might be worked, without injury. He did not believe, however, in the difference attempted to be established in the Paper, between combined steam, and superheated steam; nor did he understand the allusions made in it, to a mixture of steam and gas, as there was no gas of any kind in steam.

Mr. DORMAN had tried the Author's system of superheating steam, and a considerable gain in pressure was the result. The apparatus, which was similar to that applied by Mr. Perkins to his hot-water ovens and stoves, had, through some neglect, not worked well, the lower tubes having been nearly destroyed; but the use of it would be resumed, as soon as the necessary repairs had been effected.

The Hon. JOHN WETHERED said, in reply, that at first, he had followed in the footsteps of his predecessors, in the use of superheated steam, and like them he had found, that when it was heated sufficiently high to develop the full power, it destroyed the cylinders and slides. On considering the subject, he came to the conclusion, that the best remedy for this evil would be, to combine ordinary steam with the superheated steam, and he found, that it not only had the desired effect of regulating the heat of the latter, but that it also gave increased power. This assertion appeared to be doubted, even by some who had given him credit for re-introducing the system, and for utilising it. He would be content to dispense with half the credit, for half the emolument which others had derived from it. In his Paper, he had criticised the plan of superheating by pipes placed over the fire, but it had been said by the promoter of that system, that he had seen it in operation and had admired it; his admiration, however, had been called forth by the simplicity of the idea, that iron pipes could be made to sustain a heat of 3,000°. In his own experience, he had never found any iron capable of sustaining one-third of that heat, without oxidation, and ultimate destruction; the only metals that could resist it, were gold and platinum.

A superheating apparatus had been applied, about a year ago, to the 'Valetta,' and an account of it was published, as though it had only just been discovered, that by the employment of superheated steam, considerably less feed water was required. He had understood, that the apparatus was soon destroyed, and had never been restored. It had been remarked, with reference to the indicator cards of the 'Dee,' that the superheated steam was throttled; and that if the steam had been admitted differently, the card would have been equal to the one made by the combined steam. Now the area of the opening of the valves was the same in both cases, when those indicator cards were taken. After his plan of superheating had been in operation, for some months, in H.M.S. 'Dee,' objections were made by the Admiralty, whilst admitting that the economy was entirely satisfactory, that the pipes in the chimney were liable to be struck by the shot of an enemy, and, therefore, that the pipes could not be placed there in war steamers. Experiments were then made with the apparatus of Mr. Patridge, which failed to produce superheated steam of sufficiently high temperature to develop the full economy, and the increased power due to the system; in proof of which, he would refer to the Report of the Board of Admiralty, of the average results of twenty voyages of the 'Dee.' The indicated H.P. obtained was, with combined steam, 500 H.P.; with superheated steam, 409 H.P.; and with plain steam, 404 H.P. The communication from Mr. Dinnen referred only to experiments

made with Mr. Patridge's superheating apparatus, which, as before stated, did not obtain sufficiently high temperatures by 150°, and consequently, was but a very imperfect trial of the system of combining steam.

By the use of mixed steam, it was found, that more heat was lost in the cylinder, or was transferred into mechanical force, than with ordinary, or with superheated steam; and it was a well-established fact, which went far towards proving the correctness of the Author's theory, that a cistern of water could be boiled with combined steam, in one-third less time than with superheated steam at the same temperature. Experiments were made by a committee appointed by the Maryland Institute, U.S., from which it resulted, that with ordinary steam, and with the same pressure, in each case, upon the boiler, a cistern of water could be boiled in seventy-eight minutes; with superheated steam, in eighty minutes; and with combined steam, in forty-four minutes. It was unnecessary to reply to the doubts entertained, whether sufficient heat could be obtained in the up-take to maintain the desired temperature; experience had sufficiently proved the fact, that steam absorbed heat with greater avidity than water. He thought all would agree, that the greater the quantity of heat lost in the cylinder of an engine, the greater would be the power exerted; and in all the experiments that had been made with mixed steam, that fact was distinctly evident. Allusion had been made to the saturation of steam with water. He had thoroughly examined that subject, and had measured the water with the greatest accuracy; the result was, that combined steam from six parts of water, would effect as much work as ordinary steam from ten parts of water. This entirely overthrew the theory of those who asserted, that they could measure the work done, by the quantity of water which passed through the cylinder. No doubt, a vast deal of water was mechanically mixed with steam, in its passage from the boiler to the cylinder, besides what was condensed in the cylinder itself. Most of those who doubted the superiority of combined over superheated steam, had never tried it; for experience had proved, that if the steam was sufficiently superheated, and was then mixed down to a proper temperature, a greater power was exerted by the mixed, than by the superheated steam.

He had not desired to advance any crude theory, but had simply brought forward facts. The rationale of combined steam, given in the Paper, was exactly that of Professor Regnault, President of the Institute of France, after investigating the experiments in Paris. The difference between superheated steam and combined steam consisted in this; that the former being of a gaseous nature, was a bad conductor of heat, and parted with it with difficulty; whereas combined steam, being pure vapour, and a

better conductor of heat, parted with it more readily, and left more in the cylinder of the engine, to be converted into mechanical power.

On first making this discovery, he applied to the Government of the United States. The Secretary to the Navy took so much interest in the subject, that he directed the Engineer-in-Chief of the Navy, to proceed to New York to investigate it. The result of those investigations was to prove an economy of combined steam over ordinary steam, of 52·5 per cent., and over superheated steam, of 25 per cent. He then submitted his plan to the Board of Admiralty in London, by whom every facility was given for carrying out his experiments. He availed himself of this opportunity to express his acknowledgments for the kindness and courtesy extended to him by the officers of the Admiralty. He next introduced his system in France, and a committee was appointed by the Minister of Marine to carry out experiments with a small engine. The results of those experiments showed a superiority of combined steam over ordinary steam, of 52·7 per cent., and over superheated steam, of 24 per cent. It was very remarkable, that the experiments ordered by the French and American Governments, should have given results within about 1 per cent. of each other. The British Admiralty tried the system upon a larger scale, in their own yacht, the 'Black Eagle,' and also in the 'Dee,' of 200 H.P., and the average results of twenty voyages were those already given. These were facts well authenticated by the Reports of the French Government, by the Reports of the British Admiralty, and by the Reports of the trials made by the United States Government, given in the "Franklin Journal."

He was fully aware of the difficulties which attended the introduction of any new system of this kind; he knew the strong influence of old theories gained from limited experience; he knew also, that the facts he had established by years of experience, conflicted with those theories. The results he had obtained were said to be anomalous; but in any important discovery, they were seldom, at first, capable of explanation. It seemed highly improbable, that a boiler could be made to feed itself by its own steam pressure, yet Mr. Giffard had lately given ocular demonstration of the fact. When theories and facts apparently came into conflict, theories must yield, and be made to conform with the results of experience.

Mr. Bidder,—President,—said, the subject was one of great importance, and the discussion upon it had enabled the Meeting fairly to appreciate the rationale of the advantages which had been derived from superheating steam. It had been the unanimous opinion of those who had taken part in it, that for the practical introduction of this principle to the steam engine, Engineers were

indebted to the Author of the Paper. He was also possessed of that energy and perseverance for which his countrymen were so remarkable, and which had enabled him to make an impression, even upon the Board of Admiralty. The President was afraid, that any English Engineer could hardly have hoped to achieve the same success. There appeared to be, in the public departments of this country, a great leaning towards inventions introduced from abroad; this was advantageous in one respect, for it attracted, at all times, the best talent from other countries. He thought, however, that the Author had not clearly established his case in favour of combined steam. It rested upon the facts he had quoted, and not upon any explanation of the rationale which ought to produce such success as he claimed for it. The President was, generally, inclined to look with suspicion, upon all improvements connected with steam, or applied to other machinery in daily use; for he felt, that the fact of special attention being directed to any part of it, would induce more care, which alone would be attended with beneficial results, and they were supposed to arise from the particular modification then in course of being tested. Such was invariably the case, with regard to the permanent way of railways. Where any supposed improvement was tried upon a length of half a mile, or a mile of road, and the attention of the platelayers was directed to it, the almost certain result was, that that particular piece of road stood remarkably well. It was on that account, that he thought the case in favour of combined steam was scarcely satisfactory, unless it were accompanied by a scientific explanation of the results claimed for it. He had no doubt, however, that in the arrangement made for the passage of the steam through the pipes, some advantage was obtained. But the results of the experiments in the 'Dee' were most anomalous. It seemed to have been universally admitted, that the use of superheated steam gave an advantage of from 15 to 30 per cent. over that of ordinary steam, yet in the 'Dee,' 409 H.P. were obtained from the former, and 404 H.P. from the latter, showing a superiority of only 1 per cent. Although the Meeting had been, generally, of opinion, that the benefit to be derived from the use of combined steam was less than had been claimed, it was greatly indebted to the Author for the Paper he had communicated on the subject, and the practical discussion which it had elicited.

April 3, 1860.

GEORGE PARKER BIDDER, President,
in the Chair.

The following Candidates were balloted for, and duly elected :— JOHN AYRIS, JAMES AUSTEN DICKINSON, JOHN DINNEN, R.N., DANIEL MAKINSON FOX, SILVANUS WILLIAM JENKIN, EDWARD FRANCIS MURRAY, WALTER MONTGOMERIE NEILSON, and HENRY JAMES ROUSE, as Members; and WILLIAM BRANCH POLLARD, Junior, WILLIAM RIGBY, and ROBERT SHARPE, as Associates.

The discussion upon the Paper, No. 1,010, "On Combined Steam," by the Honourable John Wethered, was continued throughout the evening, to the exclusion of any other subject.

In pursuance of the notice on the card of the Meetings, it was proposed, and resolved unanimously :—

"That in order to insure a fuller attendance of Members than could be obtained on Easter Tuesday, the Meeting be adjourned until Tuesday evening, the 17th of April."

April 17, 1860.

GEORGE PARKER BIDDER, President,
in the Chair.

THE President announced to the Members, that the late Mr. Joseph Miller, for many years a Member of Council, had kindly bequeathed to the Institution the sum of Five Thousand Pounds, of which Three Thousand Pounds would be receivable immediately, and Two Thousand Pounds on the demise of a gentleman resident in the West Indies. The funds of the Institution would thus be materially augmented, as there would also be soon receivable, the bequest of Two Thousand Pounds from the late Mr. Robert Stephenson. To these amounts must be added the sum of nearly Five Thousand Pounds, bequeathed by the first President, Mr. Telford; of Two Hundred Pounds, presented by Mr. Charles Manby; and of One Thousand Pounds, which had recently been invested out of income. The total invested property would thus, ultimately, become:—

	£.	s.	d.
Bequest from Thomas Telford	4,894	12	4
Donation from Charles Manby	200	0	0
Bequest from Robert Stephenson . .	2,000	0	0
Bequest from Joseph Miller	5,000	0	0
Invested by the Institution	1,000	0	0
	£13,094	12	4

No. 1,018.—"On the Efficiency of various kinds of Railway Breaks; with Experimental Researches on their Retarding Powers." By WILLIAM FAIRBAIRN, F.R.S., M. Inst. C.E.

AMONG the various improvements which are in course of introduction into the working of railways, in order to diminish the dangers of travelling, attention is now specially directed to increasing the power of retarding trains, by means of various kinds of breaks. Few objects can be of more importance to safety in travelling, than the ability to destroy the momentum of trains with ease and rapidity, not only in ordinary cases where they have to be brought to a stand, as at stations, &c., but under special circumstances, such as obstructions perceived by the engine driver,

when the power of immediately retarding the train being within reach, might be the means of altogether preventing collision, or at least, of diminishing the violence of contact. It is already allowed by many of those connected with railways, and it has been expressly stated by the Lords Commissioners of the Railway Department of the Board of Trade, that the amount of break power supplied to trains is, in most cases, insufficient. In the Report of the Railway Department for 1857,[1] ten accidents are enumerated which might have been materially modified, if indeed not altogether prevented, by an increased retarding power under easy command.

Upon this subject the most important communication hitherto published, is the Report prepared by Colonel Yolland, for the Railway Department of the Board of Trade. It gives the results of a large number of experiments with heavy trains, at high velocities. The breaks experimented upon were those most generally employed, and which appeared to have been most successfully used. They were the steam break of Mr. M'Connell, (M. Inst. C.E.,) the continuous break of Mr. Fay, the continuous and self-acting break of Mr. Newall, and the self-acting break of M. Guérin. The special results arrived at were, the recommendation of the break of Mr. Newall, and the provisional recommendation of that of M. Guérin, for some descriptions of heavy traffic.

The present Paper is based upon an inquiry arising out of this Report. Mr. Fay felt aggrieved, that Colonel Yolland should have given the preference to the break of Mr. Newall, whilst at the same time, it was admitted that, in respect to retarding force, his own breaks manifested some superiority. This decision was, doubtless, not given without reason. Retarding force is but one of the elements of comparison; and Colonel Yolland states it as his opinion, that Mr. Newall's break "is the more comprehensive machine," and "accomplishes more objects than are aimed at by the other." Nevertheless, a question of efficiency arose, which could only be settled by additional trials. Hence, upon application being made to the Directors of the Lancashire and Yorkshire Railway, Mr. Fay obtained permission for a further investigation of the subject. The Author was invited to arrange the conditions of the trial, and to superintend the experiments, in order that they might be impartially carried out. The original instructions were conveyed in the following extract from the "Minutes of Proceedings of the Rolling-Stock Committee of the Directors, dated Manchester, September, 1858:"—

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[1] *Vide*, "Report upon the Accidents which have occurred on Railways, during the year 1857." Folio. London, 1858. Page 11.

"Letter from Mr. Fay read, applying for an investigation as to the statements in the recent Report of Colonel Yolland, of the Board of Trade, respecting his break.

"After a long conversation it was arranged, that the two breaks should be tried, side by side, on two lines of rails, under exactly similar conditions, (say on the Oldham Incline, or some other suitable line); and that a second experiment should be tried, reversing the lines of rails on which the breaks are respectively run. Also, that Mr. Fairbairn should be invited to superintend the experiments, and to fix the conditions thereof, and afterwards, to give his opinion as to the respective merits of the two breaks.

"In this arrangement, Messrs. Newall and Fay both concurred."

On the receipt of these instructions, the Author agreed to enter on the investigation. The objects he had in view were; first, to ascertain the respective retarding power of each of the competitive breaks; and, secondly, to obtain some data in regard to the rapidity with which a train, with an engine and tender attached, could be brought to a stand, when travelling at a high rate of speed, so as to determine the value of the continuous and self-acting breaks, as compared with those ordinarily in use, and with others recently introduced. The Report founded upon these experiments was sent to the Board of Directors, some time since.

In the following Paper a more comprehensive purpose is aimed at. It is wished not only to place the experiments permanently on record, for the guidance of the profession, and as an addition to existing knowledge on the subject, but also to incorporate with them the experiments previously referred to, in order that more general results, as to the comparative value and power of such breaks, may be arrived at. The Author is the more induced to attempt this, because such experiments appear, hitherto, to have remained as isolated results, without being reduced to any common standard of comparison. To effect this reduction, a few dynamical laws will suffice. The case of trains on a dead level may first be considered. Suppose a train impelled by a locomotive engine, until it attains a uniform measured velocity, v, in feet per second; that then the breaks are applied, and the train brought to a stand, after passing a distance, s, in feet; it is required to find a measure of the force, by which the momentum has been destroyed. Inasmuch as the breaks act by friction, which may be considered, with sufficient accuracy, to be uniform throughout the operation of breaking, the train may be assumed to be stopped by a uniformly retarding force, acting through the space s, and subject to the dynamical laws for such forces. If the retarding force in this case is called f, consisting, mainly, of the friction of the breaked wheels, and, for simplicity,

including also the friction of the axles, resistance of the air, &c. :—

then, $$f = \frac{v^2}{2\,s} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

But supposing, as is generally the case, that the retarding force of the breaks is proportional to a part of the weight of the train only, that is, that the retarding force generated varies as the weight on the rubbing surfaces, and supposing the breaks to be applied to a few carriages only; putting w for the weight of the break carriages in tons, and W for the weight of the train :—

then, $$f_1 = \frac{W\,v^2}{2\,w\,s} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

which gives the retarding force per unit of mass of the break carriages; or, in other words, f_1 is the diminution of the velocity of the train, in feet, in one second of time.

It will be convenient to reduce this force to terms of weight, instead of mass. Call f_2 the retarding force in lbs. per ton weight of the break carriages :—

then, $$f_2 = f_1 \times \frac{2{,}240}{32{\cdot}19} = 69{\cdot}587\,f_1 \quad . \quad (3)$$

Again, supposing that, instead of being on a level line, the breaks are applied on an incline. Then the action of gravity will cause the train to go further, if it is descending the incline, or to stop sooner, if ascending, than if the line was level; and gravity is a uniformly accelerating, or retarding force, as the friction of the carriages. Hence, the net result, in distance and velocity, of a train stopped on an incline, may be supposed to arise from two forces: f, a retarding force dependent on the friction of the breaked wheels; and φ, a retarding, or accelerating force dependent on gravity, and assisting, or opposing the action of f, according as the incline rises, or falls :—

thence, $$f \pm \varphi = \frac{v^2}{2\,s} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

Now, the value of φ in terms of the inclination θ of the plane to the horizon is known, for if g be the velocity generated by gravity in one second :—

$$\varphi = g \sin \theta,$$

or, putting z for the vertical height, fallen through by the train, between the time of applying the breaks and stopping the train :—

$$\varphi = g\,z$$

$$\therefore f = \frac{v^2}{2\,s} \pm g \sin \theta;$$

or, $$f = \frac{\frac{1}{2}v^2 \pm 9z}{s} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

$$f_1 = \frac{W}{w} \times \frac{\frac{1}{2}v^2 \pm 9z}{s} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

$$f_2 = \frac{2{,}240}{g} \times \frac{\frac{1}{2}v^2 \pm 9z}{s} = 69{\cdot}587 f_1 \quad . \quad . \quad (7)$$

where the + or − sign is to be adopted, according as the gradient falls, or rises.

In the increase of the break power of trains, the principles hitherto most successfully employed have been; first, the use of steam acting direct on the breaks; secondly, the connection of several of the ordinary form of breaks, so as to unite them under the control of a single breaksman; and thirdly, the introduction of break apparatus connected with the buffers, so as to make the momentum of the train itself, available in generating a retarding force.

Mr. M'Connell's break, which is applicable only to the engine, consists of two wrought-iron sledges, each 48 inches in length and 4 inches in breadth, and turned up at the ends. These sledges are suspended from the lower side of the fire box, between the driving and the trailing wheels of the engine. The pressure is placed on them, by admitting steam from the boiler into two cylinders, each 9 inches in diameter, placed horizontally, one on each side of the fire box, above the sledges, and forcing these latter down upon the rails by means of an elbow joint. The pressure can be applied to either side of the pistons in the cylinders, according as the breaks have to be raised, or depressed. The pressure of the sledges upon the rails, calculated from the pressure of the steam in Colonel Yolland's trials, would amount to about 6 tons. On the weighing machine, however, the actual pressure was found to vary from 4 tons to 9 tons, or a mean of about 7 tons; and these anomalies he confesses himself unable to solve. The principal advantage of this break appears to be, that it is immediately applied, without exertion, and is under the control of the engine driver, who, in most cases, is the first to perceive any obstruction on the line. It will be seen, however, that although efficiently generated, the amount of retardation caused by this break is comparatively small, and, as Colonel Yolland concludes, insufficient to prevent collision in those cases in which its use would be specially desirable.

Mr. Newall's and Mr. Fay's breaks, which, in their present condition, are identical in principle, are distinguished from other breaks by this; that two, or more carriages, or, if necessary, the whole train, are fitted with break blocks, all of which are brought

under the direction of one guard, by means of a longitudinal shaft, which transfers the motion of the guard's wheel to the breaks, throughout the whole length of the train. In this way, an enormous increase of retarding power may be obtained, proportional to the weight of the carriages to which breaks are applied, and with this further and important advantage, that the retarding force is distributed equally throughout the train, instead of being accumulated at either end, and thus the shock upon the wheels and axles is much diminished. Mr. Newall and Mr. Fay have also adopted a partially self-acting apparatus of springs, by means of which the breaks are applied throughout the length of the train, on the simple release of a catch, by the guard, or the engine driver, as the case may be.

In Mr. Newall's break, the motion of the guard's, or the engine-driver's wheel, since either, or both of these may have the control of the breaks, is transferred through the medium of a short vertical shaft in the van, or tender, to the longitudinal shaft placed beneath the carriages of the train, by a pair of bevil wheels, or by a spur wheel and pinion. The longitudinal shaft passes either beneath the centre, or at one side of the carriage, under the framework; and it is connected by simple, but very effective, jointed couplings between each pair of carriages, so as to permit the free action of the buffers, and the rise and fall of the carriages with the inequalities of the line. Near to the middle of the carriage, a bevil wheel is fixed on the longitudinal shaft, which is toothed into a similar one on a short cross shaft, carrying also a spur pinion geared into a horizontal rack. Thus, on revolving the guard's wheel, this rack is drawn back, withdrawing, at the same time, the principal arm of the rocking shaft, at the centre of the carriage, and compressing a spring placed on the other side, to both of which the rack is attached by a simple connecting rod. In this position, the break blocks are off the wheels, and the break is ready for use. If the bevil wheel, or pinion in the guard's van, or tender, is now released, or lifted out of gear by a lever, or treadle, the springs throughout the train will force back the arm of the rocking shaft, which carries the levers that press the break blocks on the wheels. If it is required to put on the breaks harder, and to skid the wheels, the treadle is again released by the guard, and the pressure increased by revolving the wheel in the ordinary way. In other words, Mr. Newall and Mr. Fay provide a number of springs, or, in some cases, weights, under each carriage, in which is stored up, ready for instantaneous use, a stock of break power, derived from the one guard acting through a longitudinal shaft, communicating with every break by means of an arrangement of spur wheels and pinions. From this it will be seen, that on any emergency, the retarding force may be in-

stantly employed, by simply releasing a catch, which permits the break blocks to be forced upon the wheels, by the springs, throughout the train. In justice to Mr. Newall, who claims the earlier application of this combination of breaks, it must be admitted, that Mr. Fay has adopted identically the same principle, with very slight modification in form, or in construction.

In the class of breaks in which greater retarding power is obtained, by increasing the number of breaked carriages and combining their action, the systems just described appear the best and most comprehensive, hitherto adopted. But the Author has received from Mr. E. W. Watkin, the details of some experiments on an auxiliary break carriage designed upon a different plan. In this case, an ordinary break arrangement is employed, with a double elbow joint, to which a long vertical lever is attached, moving in an arc against the side of the van. A rope from the end of this lever is conveyed to the tender, or the guard's van, and is attached to a drum, on the axis of the ordinary guard's wheel. Hence, when the guard, or the fireman revolves his wheel to put on his own break, the rope coils upon the drum, drawing back the lever, and thus putting on the auxiliary breaks at the same time.

Belonging to the third class of breaks before enumerated, in which the momentum of the train itself is employed in generating the retarding force, there is only the break of M. Guérin, which is entirely self-acting, and is brought into use by the recoil of the buffer rods, when, by the application of the tender break, a retardation has been caused in front.[1] Colonel Yolland thus describes this break:—The buffer rods at the after end of the carriage, abut against a spring that extends across its width; one buffer rod acting against each end of the spring. This spring, instead of being fixed against the under-framing of the carriage, or the break van, in the usual manner, is moveable in a groove. On one side, the centre of the spring is secured to the draw bar, and on the other, it is attached to the arm of a short lever, fixed almost vertically over the rocking shaft, so that when the buffers are pressed in by the sudden check to the velocity, caused by shutting off the steam, by the application of the tender break in front, and by the momentum of the train in the rear, the buffer spring is carried forcibly against the lever, the rocking shaft is turned, and the break blocks are forced against the peripheries of the wheels. The breaks are prevented from being put on, when a train is required to be shunted, by a crosshead, or stop. But this provision interferes with the application of the breaks, when the train is in motion at a low velocity. For such a speed, it is assumed the tender break will be sufficient.

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xvii., p. 153.

These, therefore, are the breaks upon which the experiments have been made, and the results of which have been tabulated and classified.

EXPERIMENTS WITH MR. NEWALL'S AND MR. FAY'S CONTINUOUS BREAKS.—In carrying out the views of the Directors of the Lancashire and Yorkshire Railway, the Author arranged, in the first place, for a series of experiments on the Oldham Incline, where two similar trains of carriages, one fitted throughout with Mr. Newall's, and the other with Mr. Fay's breaks, were started alternately. After passing over a measured distance, by the action of gravity, the breaks were applied, and the distance within which the trains were respectively brought up, was carefully ascertained, as giving the measure of the break power of the trains. Each train consisted of three weighted carriages, and they were started by simply releasing a stop. Having descended, by gravity, a previously measured distance, with a uniformly accelerated velocity, they passed over a fog signal, which gave notice to the guard to put on the breaks. Then the train having been brought to a stand, the distance from the point at which the train stopped, to the fog signal, was measured back, and the train was dragged up the incline for another trial. Unfortunately, the day on which these experiments were made, proved misty and foggy, with rain at intervals, so that the rails were in the worst condition for facilitating the stopping of the trains. The significance of this fact will be seen, on comparing these results with later ones obtained in dry weather.

TABLE I.—EXPERIMENTS with MR. NEWALL'S and MR. FAY'S RAILWAY BREAKS, on the Oldham Incline, February 6, 1859.

Weather foggy and wet; gradient falling 1 in 27; weight of trains, 26 tons 10 cwt. each; no engine attached.

Mr. Fay's Flap Breaks.					Mr. Newall's Slide Breaks.				
No.	Time of Running.		Distance Run.		No.	Time of Running.		Distance Run.	
	Before Breaking.	After Breaking.	Before Breaking.	After Breaking.		Before Breaking.	After Breaking.	Before Breaking.	After Breaking.
	Seconds.	Seconds.	Yards.	Yards.		Seconds.	Seconds.	Yards.	Yards.
1	35	..	150	153	1	35	14	150	281
2	40	13	200	250	2	40	16	200	336
3	48	14	300	360	3	48	17	300	459
4	58	15	400	499	4	56	25	400	608
5	59	12	400	326	5	56	14	400	371
6	62	25	500	739	6	62	19	500	663
7	72	17	600	575	7	68	17	600	545
..	..	..	..	..	8*	63	32	500	798

* In this experiment, the self-acting part of the break only was employed.

In these experiments, the whole of the wheels were sledged, or skidded, before the train was stopped. The self-acting arrangement of springs was fitted to Mr. Newall's carriage alone. In the later experiments, it was adopted also by Mr. Fay.

Taking the mean of the number of seconds required in breaking each train, in experiments Nos. 2, 3, 4, 5, 6, and 7, which were made under precisely corresponding circumstances in the case of each break, and at similar velocities, it is found, that the train was brought to a stand:—

By Mr. Newall's break . . in 21·6 seconds,
„ Mr. Fay's „ . . „ 19·2 seconds;

or about two and a half seconds of time in favour of Mr. Fay's.

It will, however, be advisable to ascertain the precise value of the retarding force in each case, by the formulæ already given. To effect this, the initial velocity of the train at the instant of applying the breaks, must first be ascertained. For this purpose the least objectionable formula, and at the same time the most simple, is:—

$$v = \frac{2\,s}{t} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (8)$$

where v is the velocity in feet per second; s is the distance run, in feet; and t is the time of running, in seconds. From this formula the following initial velocities of the train, in feet per second, in the preceding experiments, are obtained:—

No.	Mr. Fay's.	Mr. Newall's.
1.	25·71	25·71
2.	30·00	30·00
3.	37·50	37·50
4.	41·37	42·85
5.	40·66	42·85
6.	48·38	48·38
7.	50·00	52·94
8.	—	47·61

Hence, by the equation (6), since, in this case:—

$$\frac{W}{w} = \frac{26{\cdot}5}{26{\cdot}5} = 1,$$

and therefore, $$f = f_1,$$

and $$f_1 = \frac{\frac{1}{2}\,v^2 + g\,z}{s};$$

the relative values of each description of break, and their comparative efficiency in each trial, may be derived. The retarding force of each break is found to be as follows:—

No.	Mr. Fay's.		Mr. Newall's.	
1.	1·9115		1·3246	
2.	1·7922		1·6388	
3.	1·8432		1·7030	
4.	1·7645	Mean 1·8538	1·6946	Mean 1·7436
5.	2·0280		2·0152	
6.	1·7205		1·7811	
7.	1·9167		2·0480	

Giving, as in the previous comparison, the advantage to Mr. Fay, in the proportion of 1·8538 to 1·7436, or as 1,051 to 1,000. The entire agreement of the results among themselves, and with the preceding comparison derived from the time, is sufficient evidence of the practical accuracy of the formula of reduction employed. The breaks stand, in these experiments, very nearly on an equality of merit.

The experiments in the next Table were made at Southport, upon a line more nearly level. The speed was obtained by means of a locomotive engine, which was detached, at the instant of applying the breaks, by a slip coupling. The velocity, which was maintained uniform over the last half-mile, was measured by noting the time required to pass two fog signals, placed half a mile apart. The breaks, in every trial, were applied almost instantaneously, after the report of the second fog signal, and the distance was measured after the train had come to a state of rest.

TABLE II.—EXPERIMENTS with MR. NEWALL'S and MR. FAY'S RAILWAY BREAKS, on the line between Liverpool and Southport; January 7, 1859.

Weather fine and frosty; gradient rising 1 in 485; weight of trains, 26 tons 10 cwt. each.

Mr. Fay's.					Mr. Newall's.				
No.	Time of Running ¼ Mile, in Seconds.	Speed, in Miles per Hour.	Velocity, in Feet per Second.	Distance of Pulling up, in Yards.	No.	Time of Running ¼ Mile, in Seconds.	Speed, in Miles per Hour.	Velocity, in Feet per Second.	Distance of Pulling up, in Yards.
1	42	42·85	62·86	184	1	31	58·06	85·16	240
2	40	45·	66·	206	2	30	60·	88·	Lost,
3	34	52·94	77·65	272	as also another experiment.				
4	31½	37·14	83·81	313					
5	30	60·	88·	329	Engine alone	30	60·	88·	960

The second experiment with Mr. Newall's breaks failed, in consequence of the guard applying the breaks too soon, and a third was lost from the fracture of the slip coupling.

When these results are reduced by the same formula, the following values of f_1, representing the efficiency, or retarding force of each break, are obtained:—

No.	Mr. Fay's.		Mr. Newall's.
1.	3·5125	Mean 3·6256	4·97
2.	3·4579		
3.	3·6274		
4.	3·6738		
5.	3·8566		

These experiments give a superiority in favour of Mr. Newall's breaks, in the proportion of 4·97 to 3·6256, or as 1,378 to 1,000.

The value of the retarding force, f, for the tender break, derived from the last experiment, is 1·2781, and reducing this, in proportion of the weight of the tender to the weight of the engine and tender, it becomes :—

$$f_1 = 4{\cdot}3455.$$

At this period, Mr. Fay requested permission to attach a self-acting apparatus to his breaks, as he considered they were not fairly matched against those of Mr. Newall, when applied by hand. The experiments were, therefore, postponed for two months, to enable Mr. Fay to effect this alteration. They were again resumed on the 14th of April, 1859.

TABLE III.—EXPERIMENTS with MR. NEWALL'S AND MR. FAY'S RAILWAY BREAKS, on the line between Liverpool and Southport; April 14, 1859.

Weather, dry during the first, with a slight shower during the remaining experiments; gradient falling 1 in 3,453; weight of trains, 27 tons 6 cwt.

Mr. Fay's.					Mr. Newall's.				
No.	Time of Running ¼ Mile, in Seconds.	Speed, in Miles per Hour.	Velocity, in Feet per Second.	Distance of Pulling up, in Yards.	No.	Time of Running ¼ Mile, in Seconds.	Speed, in Miles per Hour.	Velocity, in Feet per Second.	Distance of Pulling up, in Yards.
1	56½*	31·8	46·7	121⅓	1	58	31·	45·5	101
2	53¾	33·4	49·1	124	..	..	..	..	..

* Engine attached, and tender break applied.

Reducing the results, as before :—

$$f_1 = 3{\cdot}2329 \text{ with Mr. Fay's break;}$$
$$= 3{\cdot}4161 \text{ with Mr. Newall's break;}$$
$$= 2{\cdot}9956 \text{ with Mr. Fay's break and tender break.}$$

Here the superiority lies with Mr. Newall, in the ratio of 1,056 to 1,000. The experiment with the engine attached, when reduced in the ratio of the weight of the train to the weight on the wheels breaked, gives :—

$$f_1 = 4{\cdot}84.$$

It will be observed, that as the value of the retarding force of the breaks is here obtained in terms of the coefficient of friction,

for the rubbing surfaces, the efficiency of the break varies with the condition of the weather. Thus the mean of the Oldham experiments gave a retarding force of 1·7987 feet per second; the mean of the first experiments at Southport gave 4·2978, and the mean of the second, 3·3245. On each day the experiments were consistent with one another, but they differed widely, on different days, from the change in the condition of the rubbing surfaces. At Oldham, the experiments were made with the rails in a greasy condition, from fog; at Southport, in the later of the two trials, with the rails slightly wet, and in the earlier, with the rails dry, and in the best condition for breaking. This is in accordance with the experiments of M. Morin on the friction of iron on iron; in which it was found, that the coefficient of friction varied from 0·05 to 0·3, according as the surfaces were greasy, wet, or dry. This consideration must be borne in mind in estimating the results, and together with some improvements in the adjustment of the breaks, and the introduction of increased power, from time to time, will explain the discrepancies which may be found, on comparing the results obtained at different periods of the trials.

The remaining experiments upon the self-acting breaks were all made under uniform and favourable conditions; the weather was fine, and the wind blew each day from the west, or the north-west. The results, also, are uniform for these days, and there can, therefore, be no error in placing these experiments in the same Tables, and averaging them together. This classification will, therefore, be adopted as more convenient, and they will be arranged under the following heads:—

1°.—Experiments on the friction of the carriages.
2°.—Experiments with slide breaks, with the engine detached.
3°.—Experiments with flap breaks, with the engine detached.
4°.—Experiments with the engine attached to the train.

EXPERIMENTS ON THE FRICTION OF THE CARRIAGES.—These experiments were made by running the train, as before, past two fog signals, half a mile apart, to obtain the velocity, detaching the engine at the second fog signal, and allowing the train gradually to come to rest.

TABLE IV.—EXPERIMENTS with MR. NEWALL'S and MR. FAY'S RAILWAY BREAKS, on the line between Liverpool and Southport; June 2, 1859.

	Time of Running ½ Mile, in Seconds.	Speed, in Miles per Hour.	Distance run, after applying Breaks, in Yards.	Time of Running, after applying Breaks, in Seconds.	Height fallen through by Train from inclination of Line, in Feet.
Mr. Fay's . .	40·	45·	4,840	430	7·06
Mr. Newall's .	44·5	40·45	6,380	780	13·91

Reducing, as before, the normal friction of the carriages, $f = f_1$, is found to be :—

Mr. Fay's break	0·16565
Mr. Newall's break	0·10961

and therefore, f_2, or the friction per ton weight of the carriages, is :—

Mr. Fay's break	11·527 lbs.	Mean
Mr. Newall's break . . .	7·627 „	9·577 lbs.

This shows that there is a considerable difference between the friction of the two sets of carriages ; and a small correction should, therefore, be made, in the reductions of the experiments on breaks, in favour of Mr. Newall, if perfect accuracy were required. The correction, however, does not exceed one-sixtieth of the retarding force of the breaks, and may be neglected without appreciable error. These experiments were made with carriages fitted with slide breaks, and the friction of those with flap breaks was not determined.

In an experiment recorded in Colonel Yolland's Report, the friction, derived in the same way, for a train of carriages fitted with Mr. Newall's breaks, and attached to an engine and tender, amounted to 11·4 lbs. per ton. This, when allowance is made for the greater friction of the engine, nearly agrees with the Author's results.

Experiments with Slide Breaks, with the Engine detached from the Train.—The following experiments were made between the Birkdale and Amsdale Stations, on the line between Liverpool and Southport. As before, the engine was attached by a slip coupling to the train. At the quarter and the three-quarter mile posts from Amsdale, fog signals were placed, and the time of passing between these, being accurately observed by stop watches, gave the average speed of the train. At the second fog signal, the slip coupling was unfastened, and the breaks applied, instantly on hearing the report. The Author's assistant, Mr. Unwin, and other disinterested persons, were placed in the guard's van, to prevent the premature application of the breaks; and others on the engine with the driver, to see that there was no change of velocity, in passing over the half-mile in which the speed was observed. The line where these experiments took place rose, for 500 feet from the first fog signal, with a gradient of 1 in 1,087, and then fell for upwards of a mile, with a gradient of 1 in 3,543, a fall so slight, in the short space in which the trains were brought to rest, that it cannot appreciably affect the results ; and in the reductions, the line has been considered as level.

TABLE V.—EXPERIMENTS with Mr. NEWALL'S and Mr. FAY'S SLIDE BREAKS, at Southport; May, 1859.

Mr. Newall's.					Mr. Fay's.				
No.	Time of Running ¼ Mile, in Seconds.	Speed, in Miles per Hour.	Velocity, in Feet per Second.	Distance of Pulling up, in Yards.	No.	Time of Running ¼ Mile, in Seconds.	Speed, in Miles per Hour.	Velocity, in Feet per Second.	Distance of Pulling up, in Yards.
2	55	32·72	48·	56⅔	2	51	35·29	51·76	56
4	49	36·73	53·87	77	4	41	43·9	64·39	98
6	41½	Failed	..	..	5	36	50·	73·33	129
7	41	43·9	64·39	136	6	33	54·54	80·	144
8	39	46·15	67·69	140⅔	7†	33	54·54	80·	161⅔
9	34	52·94	77·64	205⅓	9‡	47½	37·89	55·58	97
10*	33	54·54	80·	192	10‡	30	60·	88·	204⅔
11†	38	47·37	69·47	260⅓	11‡	30	60·	88·	214
12‡	33½	53·73	78·8	222	..	..	..	..	..
13‡	28½	63·16	92·63	273	..	..	..	..	..

* Self-action only.
† Breaks not applied at the proper time.
‡ Train consisting of two carriages, and weighing 18 tons 4 cwt. In the other experiments, there were three carriages weighing 27 tons 6 cwt.

The trains with which these experiments were made, consisted of three heavily-weighted carriages, each with breaks to every carriage, except in the two last experiments, when, in consequence of an accident to one of Mr. Newall's carriages, the trains were reduced to two. The carriages were loaded with iron rail-chairs, so as to weigh 9 tons 2 cwt., each.

The power of these continuous breaks was well exemplified upon the 18th of May, when Mr. Fay's guard inadvertently applied the breaks, whilst the train was running at a comparatively slow velocity; the strong coupling hook which united the tender to the guard's van, was instantly snapped, and the train brought to a stand.

Making a reduction of the preceding results, the following values of $f = f_1$, representing the comparative retarding powers of the breaks in each case, are arrived at:—

$$\begin{array}{ll} \text{Mr. Fay's.} & \text{Mr. Newall's.} \\ \left.\begin{array}{r} 7\cdot9749 \\ 7\cdot0512 \\ 6\cdot9480 \\ 7\cdot4074 \\ 6\cdot5979 \\ 5\cdot3076 \\ 6\cdot3062 \\ 6\cdot0311 \end{array}\right\} \begin{array}{c} \text{Mean} \\ 6\cdot7030 \end{array} & \left.\begin{array}{r} 6\cdot7765 \\ 6\cdot2813 \\ 5\cdot0810 \\ 5\cdot4292 \\ 4\cdot8929 \\ 4\cdot6625 \\ 5\cdot2385 \\ 5\cdot5555 \end{array}\right\} \begin{array}{c} \text{Mean} \\ 5\cdot4984 \end{array} \end{array}$$

In this case, the breaks of Mr. Fay exhibit a superiority in the ratio of 6·7030 to 5·4984, or as 1,215 to 1,000; or making a correction, as above stated, for the friction of the carriages, the

relative efficiency of Mr. Fay's and Mr. Newall's breaks, would stand in the ratio of 6·553 to 5·4084, or as 1,210 to 1,000.

EXPERIMENTS WITH FLAP BREAKS, WITH THE ENGINE DETACHED.—These experiments were made in precisely the same manner as the last, the trains consisting of three carriages, with breaks to each, loaded to 9 tons 2 cwt.

Mr. Fay's.					Mr. Newall's.				
No.	Time of Running ¼ Mile, in Seconds.	Speed, in Miles per Hour.	Velocity, in Feet per Second.	Distance of Pulling up, in Yards.	No.	Time of Running ¼ Mile, in Seconds.	Speed, in Miles per Hour.	Velocity in Feet per Seconds.	Distance of Pulling up, in Yards.
1	35	51·43	75·43	158⅓	1	36	50·	73·33	132⅔
2	35	51·43	75·43	162⅔	2	36	50·	73·33	123
3*	33	54·54	80·	184	3*	35	51·43	75·43	192

* Self-action only.

Reducing the results, the comparative efficiency is:—

Mr. Fay's.		Mr. Newall's.	
5·9889	Mean 5·8718	6·7560	Mean 6·3272
5·8294		7·2870	
5·7971		4·9387	

In this case, the superiority lies with Mr. Newall, in the ratio of 6·3272 to 5·8718, or as 1,000 to 928.

EXPERIMENTS WITH THE ENGINE ATTACHED TO THE TRAIN.—These experiments were made with slide breaks, upon the same ground, and in the same manner as the last experiments. The rails also were in the same dry condition. The only difference was, that the engine and tender remained attached to the train, instead of being uncoupled, and the tender break was applied, as rapidly as possible, along with the other breaks.

TABLE VII.—EXPERIMENTS with MR. NEWALL'S and MR. FAY'S RAILWAY BREAKS, with engine not disconnected from train.

Weight of engine, 24 tons; weight of tender, average 10 tons; weight of train, 27½ tons; weight of tank engine, 30 tons.

Mr. Fay's.					Mr. Newall's.				
No.	Time of Running ¼ Mile, in seconds.	Speed, in Miles per Hour.	Velocity, in Feet per Second.	Distance of Pulling up, in Yards.	No.	Time of Running ¼ Mile in Seconds.	Speed, in Miles per Hour.	Velocity, in Feet per Second.	Distance of Pulling up, in Yards.
1	56½	31·8	46·7	121⅓	1	53	33·96	49·81	124⅔
2	53	33·96	49·81	137	2	48½	37·11	54·43	169⅓
3	43	41·86	61·39	192⅓	3	43	41·86	61·39	221
4*	35	51·43	75 43	274	..	..	..	..	..

* Tank engine.

Reducing these results, the comparative retarding force is found to be:—

Mr. Fay's,		Mr. Newall's.	
2·9956	Mean 3·0934	3·3169	Mean 3·0250
3·0184		2·9160	
3·2663		2·8422	

where the efficiency of the breaks is almost identical, Mr. Fay having an advantage in the ratio of 1,022 to 1,000.

From the above extended and somewhat laborious experiments, the following summary of results is derived:—

TABLE VIII.—GENERAL SUMMARY of RESULTS of Experiments with Mr. NEWALL'S and Mr. FAY'S BREAKS.

	Average Number of Experiments.		Average efficiency of Breaks.	
	Mr. Fay's.	Mr. Newall's.	Mr. Fay's.	Mr. Newall's.
Oldham Incline, Table 1 .	7	7	1·8538	1·7436
Southport, Table 2 . .	5	1	3·6256	4·9700
Southport, Table 3 . . .	1	1	3·2329	3·4161
Southport, Table 5 . .	8	8	6·7030	5·4984
Southport, Table 6 . .	3	3	5·8718	6·3272
Southport, Table 7 . .	3	3	3·0934	3·0250

The general average from this Table gives, for the efficiency of Mr. Fay's breaks, 4·0634, and for that of Mr. Newall's 4·1650, showing a slight superiority in favour of the latter.

The following conclusions seem borne out by these experiments:—

1st. That with slide breaks, the greater number of experiments gave a manifest superiority to Mr. Fay's.

2nd. That with flap breaks, there was a decided advantage on the side of Mr. Newall.

3rd. That when the train was breaked, with the engine attached, the results were uniform; neither Mr. Fay's breaks, nor Mr. Newall's, gaining any decided superiority.

During the whole of these trials, there was a strong feeling of rivalry, which rendered necessary the greatest caution, in order to prevent any interference, which might modify and vitiate the results. To reconcile these differences, and to obtain correct returns, the Author's assistant, Mr. Unwin, was employed to take charge of the train, and to see that the breaks were applied at the right time; also to register the velocity of the train, and the distance of pulling up, during each experiment. There is, therefore, every reason to believe, that the results recorded are a strict expression of the efficiency of the breaks, at their respective times of trial.

Colonel Yolland's Experiments on Messrs. Newall and Fay's Railway Breaks.—It may be interesting to compare with these results, the earlier experiments obtained by Colonel Yolland, on the same class of breaks, and under somewhat similar conditions of trial, as detailed in his Report to the Board of Trade, dated the 12th of June, 1858. These results do not appear to have been reduced, hitherto, to any common standard of comparison. But as they embrace a wider range of circumstances of gradient, weather, weight, &c., than in the Author's experiments, they will instructively test the method of reduction employed.

In the experiments on the Accrington Incline, the trains weighed 72 tons each, and consisted of six weighted carriages, used in all the experiments, and of three carriages fitted with Mr. Newall's, and three with Mr. Fay's breaks, respectively, and employed alternately. The required velocity was obtained, by permitting the carriages to descend a distance of from three-quarters of a mile to a mile, along the incline, which falls at the rate of 1 in 38 to 1 in 40. The initial velocity at the instant of applying the breaks was ascertained, by observing the time required to traverse the quarter of a mile immediately preceding; and the mean velocity over this distance is used in the reductions, as the initial velocity of the train, although it is slightly below the real speed, at the instant of breaking.

Table IX.—Experiments on the Accrington Incline, with Mr. Newall's and Mr. Fay's Breaks; February 27, 1858.
Weather fine.

No.		Velocity, in Feet per Second.	Gradient, falling −.	Distance of Breaking, in Yards.	Remarks.
2	Mr. Newall's	69·47	− 1 in 39	1,587	Heavier Train.
3		52·8	− 1 in 39	777	Three continuous Breaks.
4		48·9	− 1 in 39	822	
5		28·7	− 1 in 40	414	
6		69·47	− 1 in 39	1,114	
7		62·86	− 1 in 40	1,208	
9		30·7	− 1 in 39	430	
10	Mr. Fay's . .	60·	− 1 in 39	923	

Reducing the results in Table IX., the retarding force is:—

Mr. Newall's . .	1·0275	Mean 1·3231
	1·4233	
	1·3102	
	1·1363	
	1·5285	
	1·3705	
	1·1700	
Mr. Fay's		1·4754

It will be remarked, that in these experiments, the breaks were applied to a part of the train only. Hence, for comparison with the Southport experiments, a reduction must be made, to the condition of trains with breaks throughout, by the formula (6) already explained in that way:—

$$f_1 = \frac{W}{w} f.$$

The retarding force in terms of the mass of the carriages actually breaked is:—

Mr. Newall's . .	3·7955 3·4940 3·0301 4·0759 3·6547 3·1200	Mean 3·5516
Mr. Fay's	. . . .	3·9345

showing an advantage to Mr. Fay in the ratio of 1,107 to 1,000. But a comparison is here scarcely fair, seeing the disproportion in the number of experiments with each break.

Table X.—Experiments on the Accrington Incline, with Mr. Newall's and Mr. Fay's Railway Breaks; February 28, 1858.

Weather Misty.

No.		Velocity, in Feet per Second.	Gradient, falling −.	Distance of Breaking, in Yards.	Remarks.
11	Mr. Fay's	66·	− 1 in 39	2,060	Three continuous Breaks.
13		62·86	,,	1,660	
16		50·77	,,	1,070	
17		35·67	− 1 in 40	492	
12	Mr. Newall's	60·	− 1 in 39	2,142	
14		60·	,,	1,754	
15		50·77	,,	1,450	
18		69·47	− 1 in 132	880	Tender & ditto.

The results in Table X. show, that the mean of the retarding force is:—

Mr. Fay's.		Mr. Newall's.	
1·178 1·221 1·227 1·257	Mean 1·220	1·105 1·167 1·122	Mean 1·131

or with breaks throughout:—

Mr. Fay's.		Mr. Newall's.	
3·141	Mean 3·255	2·946	Mean 3·017
3·256		3·112	
3·272		2·992	
3·352			

Giving a slight advantage to Mr. Fay, in the ratio of 1,070 to 1,000.

TABLE XI.—EXPERIMENTS on MR. NEWALL'S BREAKS, between Liverpool and Preston; February 22, 1858.

Train of carriages weighing 83 tons 18 cwt.; engine, 29 tons 2 cwt.; tender, 13 tons 4 cwt.

No.		Velocity, in Feet per Second.	Gradient, rising +, falling −.	Distance of Breaking, in Yards.	Remarks.
1	Mr. Newall's	57·39	− 1 in 135	285	Tender and six Breaks.
2		48·88	− 1 in 180	208	
3		66·00	+ 1 in 135	206	
4		45·52	+ 1 in 168	246	Tender and self-action of six Breaks.
6		57·39	− 1 in 150	276	Tender and six Breaks.
7		48·88	− 1 in 130	204	

Reducing as before, these data give:—

$$f = \left.\begin{array}{l}2\cdot165\\2\cdot095\\3\cdot285\\2\cdot204\\2\cdot201\end{array}\right\}\text{Mean } 2\cdot390$$

or, reduced in the ratio of the weight on the wheels breaked to the weight of the train:—

$$f_1 = \left.\begin{array}{l}4\cdot304\\4\cdot164\\6\cdot530\\4\cdot381\\4\cdot375\end{array}\right\}\text{Mean } 4\cdot671$$

This agrees with the value $f_1 = 3{\cdot}5516$, obtained in the first experiments at Accrington, with the rails dry, and is in excess of the value $f_1 = 3{\cdot}017$, obtained with the rails wetted by the mist.

For experiment No. 4, with the self-action of the breaks alone, $f = 1{\cdot}211$, or about one-half the full break power.

TABLE XII.—EXPERIMENTS between Preston and Liverpool, with Mr. NEWALL'S RAILWAY BREAKS; February 22, 1858.

Weight of train, 101 tons, 1¾ cwt.; weight on breaks, 71 tons, 19½ cwt.

No.		Velocity, in Feet per Second.	Gradient, rising +, falling −.	Distance of Pulling up, in Yards.	Remarks.
8	Mr. Newall's	73·33	0	196	Tender and seven continuous Breaks.
9		57·39	+ 1 in 402	130	
10		44·	0	107	
11		60·	− 1 in 120	167	

Reducing these results:—

$$f = \left.\begin{matrix} 4\cdot567 \\ 2\cdot975 \\ 3\cdot015 \\ 4\cdot118 \end{matrix}\right\} \text{Mean } 3\cdot668$$

or, when the train is breaked throughout:—

$$f_1 = \left.\begin{matrix} 6\cdot406 \\ 4\cdot173 \\ 4\cdot229 \\ 5\cdot776 \end{matrix}\right\} \text{Mean } 5\cdot146$$

This would seem to indicate, that the breaks act more efficiently, the more nearly they are applied throughout the whole train.

TABLE XIII.—EXPERIMENTS between Liverpool and Preston, with Mr. NEWALL'S BREAKS; February 23, 1858.

No.		Velocity, in Feet per Second.	Gradient, rising +, falling −.	Distance of Pulling up, in Yards.	Remarks
1	Mr. Newall's	77·65	− 1 in 204	314	All the Breaks.
2		73·33	0	179	
3		52·8	0	183	All but the Tender.
4		73·33	− 1 in 132	227	All the Breaks.
5		66·	+ 1 in 135	189	
6		73·33	0	249	
7		62·86	− 1 in 150	208	
8		44·	− 1 in 700	138	
9		77·65	− 1 in 120	235	

Reducing:—

$$f = \left.\begin{matrix} 3\cdot3582 \\ 5\cdot0068 \\ 3\cdot7041 \\ 4\cdot0797 \\ 3\cdot5992 \\ 2\cdot9516 \\ 2\cdot2922 \\ 4\cdot0081 \end{matrix}\right\} \text{Mean } 3\cdot6249$$

Or, when further reduced in the ratio of the weight of the whole train to the weight on the wheels breaked :—

$$f_1 = \left.\begin{matrix} 3\cdot9660 \\ 5\cdot9130 \\ 4\cdot3745 \\ 4\cdot8181 \\ 4\cdot2506 \\ 3\cdot4858 \\ 4\cdot7335 \end{matrix}\right\} \text{Mean } 4\cdot5057$$

The preceding results obtained by Colonel Yolland are as follows :—

	Mr. Fay's.	Mr. Newall's.	
Engine detached	3·9345	3·5516	Dry.
	3·255	3·017	Wet.
Engine attached		4·671, 5·146, 4·505	Mean 4·774

Table XIV.—Experiments on Mr. M'Connell's Steam Sledge Break, between Bletchley and Oxford; January 19, 1858.

The engine weighed 29 tons; the tender 14 tons 10 cwt.; the carriages 102 tons 9 cwt.; the guards' vans 10 tons 4¾ cwt.; steam sledges assumed at 7 tons 2 cwt.

No.		Velocity, in Feet per Second.	Gradient, rising +, falling −.	Distance of Pulling up, in Yards.	Remarks.
1	Mr. M'Connell's Steam Break.	27·5	+ 1 in 150	430	None.
2		32·19	+ 1 in 142	285	Steam and Guard's.
3		19·35	+ 1 in 142	163	Guard's.
4		52·8	− 1 in 214	590	All.
5		60·	− 1 in 149	870	Steam and Tender.
6		48·88	− 1 in 209	673	All.
7		36·67	− 1 in 1,430	623	Steam.
8		55·	− 1 in 163	880	All.
9		55·	0	763	Tender and Guard's.
10		57·39	0	1,320	Steam.
11		52·8	− 1 in 2,211	496	All.
12		60·	0	540	All.
13		55·	+ 1 in 2,211	345	All.
14		47·14	0	538	Tender and Guard's.
15		47·14	− 1 in 452	388	All.
16		62·86	+ 1 in 163	669	All.
17		57·39	0	880	Tender and Guard's.
18		55·	+ 1 in 209	1,194	Steam.

Reducing these results:—

f = 2	0·03793	11	0·93677
3	0·01562	12	1·11111
4	0·93791	13	1·42800
5	0·90567	14	0·64824
6	0·74567	15	1·02560
7	0·38224	16	0·78690
8	0·77041	17	0·62379
9	0·66076	18	0·42225
10	0·41586		

Separating those experiments which were made on different breaks, and taking the mean of those made on the same, the value of each break respectively, is as follows:—

For the guard's break	f = 0·1562
„ tender break	0·4989
„ steam break	0·4373
„ steam and tender breaks	0·9057
„ steam and guard's breaks	0·3793
„ guard's and tender breaks	0·6443
„ guard's, steam, and tender breaks	0·9678

These numbers represent the actual proportion of the break power supplied in the experiments by each break, or set of breaks. The efficiency of the breaks, in relation to the weight upon them, is:—

For the guard's break	f_1 = 2·2268
„ tender break	5·0216
„ steam break	9·1176
„ steam and tender breaks	6·1197
„ steam and guard's breaks	3·1930
„ guard's and tender breaks	3·8014
„ guard's, steam, and tender breaks	4·4365

This shows, that in proportion to the weight upon it, a sledge break, which can be applied instantly, acts most efficiently.

Colonel Yolland's Experiments on M. Guérin's self-acting Break.—The train, in the first four experiments, consisted of an engine, tender, and nineteen carriages, two being fitted with M. Guérin's breaks. The total weight of the train was 151·88 tons. In the remaining experiments, two ordinary break vans were substituted for M. Guérin's, the total weight being then 152·8 tons.

TABLE XV.—EXPERIMENTS between Erith and Woolwich; August 27, 1858.

No.		Velocity, in Feet per Second.	Gradient, rising +, falling −.	Distance of Pulling up, in Yards.	Remarks.
1	M. Guérin's Breaks	50·78	− 1 in 912	597	Tender and two Guérin Breaks.
2		62·86	0	738	
3		57·39	0	552	
4		45·52	+ 1 in 912	395	
5	Ordinary Break Vans.	48·57	− 1 in 912	359	Tender and two ordinary Breaks.
6		66·	0	593	
7		50·77	0	521	
8		52·8	+ 1 in 912	510	

Reducing these results:—

M. Guérin's Breaks.		Ordinary Breaks.	
0·075488	Mean 0·0870	0·11300	Mean 0·1013
0·089238		0·12243	
0·099445		0·08245	
0·083898		0·08757	

From these experiments, M. Guérin's breaks appear to be less efficient than two equally heavy break vans, of the ordinary description, when used in conjunction with a tender break, in the ratio of 1,165 to 1,000.

The value of f_1 for the mean of these experiments, gives:—

For M. Guérin's break . . . . 0·5169
„ the guard's ordinary break . . . . 0·5874

EXPERIMENTS WITH MR. INGRAM'S AUXILIARY BREAK, ON THE MANCHESTER, SHEFFIELD, AND LINCOLNSHIRE RAILWAY.—When these experiments were made, the weather was, unfortunately, bad, rain falling the whole time. The train weighed 124 tons $\frac{1}{4}$ cwt.; the tender, 17 tons; the carriages to which Mr. Ingram's break was applied, 25 tons $17\frac{1}{2}$ cwt.

TABLE XVI.—EXPERIMENTS with MR. INGRAM'S Breaks; October 18, 1858.

No.		Velocity, in Feet per Second.	Gradient.	Distance of Pulling up, in Yards.	Time in Stopping, in Seconds.
3	Mr. Ingram's Break	46·9	1 in 124	870	90
3		44·0	1 in 124	795	77
4		51·3	1 in 130	768	65
7	Tender only	54·2	1 in 120	1,320	134
9		46·9	1 in 120	1,152	114

Reducing these results, on the assumption that the gradients were all falling ones:—

Mr. Ingram's Break.		Tender Break.	
$f = $ 0·68096, 0·66545, 0·81870	Mean 0·7217	0·63921, 0·58646	Mean 0·6128

Hence, f_2 = with Mr. Ingram's break . 3·4619
the tender break . . 4·4712,

Mr. Ingram's break thus showing a somewhat less efficiency than the tender break.

Final Reduction of the Retarding Force to Units of the Weight of the Break Carriages.—In the preceding reductions, it has been found most convenient to learn the retarding force, in terms of the mass of the train. For practical purposes, however, it will be more convenient to state the retarding force in terms of the weight upon the break carriages, and, to be guided by precedent in this matter, it seems best to state the retarding force, in lbs. per ton weight, on the breaked wheels; that is, in the same terms as the normal friction of the train is usually stated. Calling, therefore, f_2 the mean resistance in lbs. per unit of tons, in the moving mass of all the forces tending to destroy motion, of which the principal is the friction of the break:—

then, $$f_2 = f_1 \times \frac{2{,}240}{32{\cdot}19} = 69{\cdot}587\, f_1.$$

Ordinary Breaks.

	Retardation, in lbs. per ton, on Wheels Breaked.	
Guard's van	154·9	. Yolland
Tender break	349·4	. „
Tender and guard's break	264·5	. „
Tender break	311·0	. M. S. & L. Ry.

All the above results, with the exception of the last, were obtained in dry weather.

Tender break	302·4	. Fairbairn

Mr. Newall's Breaks.

Table		Mean Retarding Force, in lbs. per ton weight of Breaked Carriages.	
1.	Slide breaks (wet and foggy) .	121·3	. Fairbairn
3.	„ „ (slightly wet) .	237·7	. „
2.	„ „ (dry and frosty) .	345·8	. „
5.	„ „ (dry and warm) .	382·6	. „
4.	Flap breaks (dry and warm) .	440·3	. „
9.	„ „ (dry) . . .	247·1	. Yolland
10.	„ „ (misty) . . .	209·7	. „
11.	„ „ (dry) . . .	325·4	. „
12.	„ „ (dry) . . .	358·9	. „
13.	„ „ (dry) . . .	313·5	. „

The mean of the Author's experiments from Tables II., IV. and V., gives the retarding force at 389·6 lbs. per ton. The mean of Colonel Yolland's, from Tables IX., XI., XII., XIII., is 311·2 lbs.; or omitting Table IX., 332·6 lbs. Bearing in mind, that the Author's results were obtained under circumstances of competition, and that there was, in consequence, the greatest care in the adjustment of the breaks, the above results agree sufficiently well. Hence also, may be observed the very large diminution of the retardation of the breaks in wet and foggy weather. In wet weather, the retardation does not appear to exceed 200 lbs. per ton, and in foggy weather, with the rails greasy, it appears that it may be reduced to 121 lbs., or nearly one-fourth of the maximum in dry warm weather.

Mr. Fay's Breaks.

Table		Mean Retarding Force, in lbs. per ton weight of Break Carriages.	
1.	Flap breaks (wet and foggy)	129·0	Fairbairn
3.	„ „ (slightly wet)	224·9	„
2.	„ „ (dry)	252·2	„
4.	„ „ (dry)	408·6	„
5.	Slide breaks (dry)	466·4	„
9.	„ „ (dry)	273·7	Yolland
10.	„ „ (misty)	226·5	„

There the maximum retardation amounts to 466·4 lbs. per ton, or nearly one-fifth of the weight of the breaked carriages. The mean of Tables 2, 4, 5, in dry weather, gives 375·7 lbs. per ton.

Mr. M'Connell's Steam Break.

Table XIV.	Mean Retardation, in lbs. per ton weight, on Wheels and Sledges Breaked.	
Guard's van	154·9	Yolland
Tender break	349·4	„
Steam break	634·4	„
Steam and tender breaks	425·8	„
Steam and guard's breaks	222·1	„
Guard's and tender breaks	264·5	„
Guard's, steam, and tender breaks	308·7	„

These reductions seem to show, that in proportion to the weight upon it, the sledge break is more efficient than any break applied to the wheels. Of course, it is not asserted, that the sledge break could be employed in lieu of the present arrangement; but that it renders useful, in retarding the train, a larger proportion of the weight on it.

M. Guérin's Break.

Table XV.	Mean Retarding Force, in lbs. per ton, on Break Carriages.	
M. Guérin's and tender break .	35·9 .	Yolland.
Ordinary van and tender break .	40·8 .	„

Both these breaks were, for some reason, acting inefficiently.

Mr. Ingram's Break.

Table XVI.	Mean Retarding Force, in lbs. per ton weight of the Carriages Breaked.	
Mr. Ingram's and tender break	240·9 .	M. S. & L. Ry.

This break appears to act with something less than the average efficiency.

General Summary.

		Ratio of weight on Breaks, to retarding force generated by them, or mean co-efficient of friction for each Break.
Mr. Newall's, (dry)	Fairbairn	from 0·1544 to 0·1965
„ (wet)	Fairbairn	0·0542
Mr. Fay's (dry)	Fairbairn	from 0·1126 to0·2082
„ (wet)	Fairbairn	0·0576
Mr. Newall's (dry)	Yolland	0·1116
Mr. Fay's (dry)	Yolland	0·1020
Mr. Ingram's (wet)	.	0·1075
Mr. Guérin's (dry)	.	0·01048
Mr. M'Connell's steam break	.	0·28325

That is, the retarding force generated by these breaks varies from $\frac{1}{100}$th to $\frac{5}{18}$ths of the weight of the carriages to which breaks are applied, and is, ordinarily, from $\frac{1}{10}$th to $\frac{1}{5}$th.

This agrees very well with the deductions from experiments on the friction of metal on metal, which give, for smooth surfaces, a coefficient varying from 0·15 to 0·2, or nearly identical with the best experiments above reported.

Practical Formulæ. — To find the distance on a level line, required to bring a train to a stand by breaking:—

Let s be the distance of pulling up, in yards.
v the velocity of the train, in feet per second.
w the weight on the breaked wheels, in tons.
W the total weight of the train, in tons.
θ the inclination of the incline to the horizon, if the train is on a gradient; so that if the incline rises

$$1 \text{ foot in } x \text{ feet, then } \sin\theta = \frac{1}{x}.$$

g the action of gravity = 32 19.

Then, if the train is breaked throughout, and on a level line:—

$$s = \frac{v^2}{6 f_1};$$

and, if breaks are applied to a part of the train only:—

$$s = \frac{v^2}{6 f_1} \times \frac{W}{w};$$

or, if the train is on an incline:—

$$s = \frac{v^2}{6 f_1 \pm 6 g \sin \theta} \times \frac{W}{w},$$

where the + or − sign is to be taken, according as the incline falls, or rises.

The value of the coefficient f_1, must be selected from the Tables of experiments already given, that coefficient being selected, which was obtained under circumstances most nearly approaching those of the case to be determined.

Thus, if the trains are stopped by the friction of their bearings, &c., without the application of breaks, $f_1 = 0{\cdot}13$ (mean), and $6 f_1 = 0{\cdot}78$.

If the breaks are ordinary guard and tender breaks, applied together, $f_1 = 4$, and $6 f_1 = 24$, approximately.

For breaks, such as Mr. Newall's and Mr. Fay's, acting with maximum efficiency, $f_1 = 5{\cdot}5$ to $6{\cdot}5$, and $6 f_1 = 33{\cdot}0$ to $39{\cdot}0$.

Thus, supposing it is required to ascertain the distance in which a train weighing 60 tons, with breaks to 20 tons weight of the carriages, would be brought to rest, in ascending an incline of 1 in 27, at a velocity of 60 feet per second; then taking $f_1 = 4$:—

$$s = \frac{v^2}{6 f_1 + 6 g \sin \theta} \times \frac{W}{w}$$

$$= \frac{(60 \times 60)}{6 \times 4 + 6 \times 32{\cdot}19 \times \frac{1}{27}} \times \frac{60}{20} = 116 \text{ yards.}$$

If the rails are wetted by rain, the value of the coefficients given above must be taken at one-third less, and if greasy, their value may be reduced by as much as one-half, or three-fourths.

It is convenient, in some cases, to estimate the breaking power in time, rather than in distance. Now, theoretically, putting t = the time of breaking in seconds:—

then, $$t = \frac{v}{f}.$$

In practice this does not hold strictly true:—

hence, $$t = \frac{v}{f} - x,$$

where x is a constant to be derived from the experiments:—

$$\therefore x = t + \frac{v}{f}.$$

Now, from the Oldham experiments:—

For Mr. Fay's breaks, x = 3, 6, 8, 8, 3, 8.
For Mr. Newall's breaks, x = 4, 2, 5, 0, 7, 8, 9.
hence, mean, x = 5·4.

$$\therefore t = \frac{v}{f} - 5{\cdot}4 = \left(\frac{v}{f_1} \times \frac{W}{w}\right) - 5{\cdot}4.$$

The above formulæ will be found sufficient for the purpose of ascertaining the amount of break power required to arrest the motion of any train, within such a distance as may be considered safe by the Railway Company, or by the Engineer; or in any given case, to determine the distance within which a train of any required weight may be stopped, when travelling at any velocity.

[Mr. SINCLAIR

Mr. SINCLAIR said, that some years ago, he had seen the apparatus of Mr. Newall, and from the experiments with it which he then witnessed, he thought it an improvement. But he was not able to enter into a comparison of the respective merits of that, and the system introduced by Mr. Fay, as he had never seen the latter; but he understood from the Paper, that the principle of the two was so nearly alike, that the results might, naturally, be supposed to be similar. It should, however, be observed, that both systems were tried under conditions peculiarly favourable, and were not put to the test of the ordinary working of a train. It appeared to him, that to obtain their full effect, they required to be very nicely adjusted, so that the breaks might bear equally. From the little he had seen of Mr. Newall's break, he thought that when it was applied under the ordinary conditions of railway service, particularly when it was used on lines where the train was habitually composed of various descriptions of carriages, it was not calculated to supersede the ordinary break. He would qualify that statement, however, by adding, that it was a long time since he had seen it in operation, and he had not had proper means of making accurate observations. If these breaks, after having been tried under the ordinary conditions in which they must be worked in the service of a railway, exhibited advantages over the ordinary break, he had no doubt, that a fair trial would be given them by the various railway companies.

Mr. HEMANS remarked, that both these breaks must be good and very efficient, to be able to stop a train, running with velocity down an incline of 1 in 27, which was, probably, the steepest gradient that could be found on any railway. It was stated in the Paper, that the train was stopped in twenty seconds, but the distance within which the stoppage was effected was not given in that particular instance. Those distances appeared to have varied from 153 to 575 yards.

Mr. BAMBOROUGH believed the distance, in that case, was 300 yards, and that the velocity of the train was 58 miles an hour, the rails being dry at the time. The velocity of the train on which the experiments were made, was, generally, between 36 miles and 40 miles per hour.

Mr. VIGNOLES said, the remarks he should offer would be of a general character. From the practical results recorded in the experiments made by the Author, it appeared, that Mr. Newall's and Mr. Fay's breaks were upon a par with each other; with the priority of invention, this Institution had not to deal. Although he had been present at a great number of experiments made with various kinds of breaks, he had never yet seen one which would, under all circumstances, efficiently replace the ordinary break now in use. One of the most interesting points in these experi-

ments, was the astonishing difference which the varying state of the weather, and of the rails, produced on the action of the breaks. It was a question in which Engineers were particularly interested at the present moment. The extension of the railway system to almost all parts of the world, had necessitated the occasional introduction of exceedingly steep inclines, often passing over mountain ranges, subject to fogs and rain: thus causing forced retardations of every kind, and severely testing the efficiency of the breaks. The conclusion at which he had arrived from careful observation was, that although many ingenious improvements had been suggested, yet the old break, combined perhaps with the steam break on the engine, was still the most successful.

Mr. Bramwell had long been of opinion, that the break upon the guard's van, now generally in use, was the worst that could be designed, and he thought the great care taken in fitting it, caused the effects of the error to be fully felt. His opinion was based on the following consideration. The ordinary break was supposed to apply the break block to each of the wheels of the carriage, whether four, or six in number. Each break block was worked by a lever, keyed fast on a shaft, fitting and working in bearings, and it was only when all the wheels were in the same exact condition, when all the blocks were of equal size, and when all were equally worn, that it was possible to get the action of the break to bear upon them all, at the same time. But taking into consideration the various qualities of wood used for the blocks and their unequal wear, it could readily be understood why it so commonly happened, in practice, that only two of the wheels were acted on by the break, and that even those two were retarded, not by the blocks acting efficiently on both, but by one block acting on one wheel, and transmitting the strain through the axle to the other. With the present construction of break, accurate fitting involved bad results in the working; but if the shaft, instead of fitting in a bearing, were laid in a slot hole, so that there could not be a pressure upon any one wheel until it was equal upon all, he thought the break would be more efficient. The old waggon break, where the shaft hung in a sling, was even better than that which was now fixed, at great expense, in the guard's van. In America, where there were generally eight wheels to each car, the breaks were made so as to be capable of being put into action from either end of the car, and were so arranged, that all the wheels had an equal amount of pressure; chains were used as a means of connection. In his opinion, if there was less good workmanship, but more common sense employed in the construction of breaks, and more attention was given by the guards, the apparatus would be far better than at present.

Mr. Wightman remarked, that it was possible to have too much

break power as well as too little. The system of using four, or more break carriages in a train, caused, in his opinion, too much reliance to be placed upon them, and encouraged the engine driver to maintain the speed up to the last moment, depending entirely upon the guard for stopping the train. The ordinary break of the guard's van, and that on the tender of the engine, constituted as good a system as any hitherto suggested. He did not think, that long continuous breaks were likely to serve the desired purpose, so well as the inventors imagined. Those fitted with bars were, probably, safer than those fitted with chains. He had not seen the application of Mr. Newall's break upon a train, but a somewhat similar plan was in operation upon the North London Railway, where the break was applied, simultaneously, to four carriages, and the train was brought up within a very short distance. But he doubted, whether the train could be stopped sufficiently quick to prevent a collision, supposing some impediment to be suddenly seen on rounding a sharp curve. The President could best judge of the effect which the sudden stoppage of a train would produce upon the passengers. A six-wheeled tender, and a guard's break with all the wheels skidded, would be found, in his opinion, quite as usefully powerful as the breaks described in the Paper.

In answer to a question from the President, Mr. Wightman said, that on the North London Railway, the engine drivers sometimes entered the stations at a greater velocity than formerly, depending upon the power of the break for arresting the train.

Mr. Hawksley said, this was a question upon which, though not practising as a Railway Engineer, he had some experience. He confessed, that he had not been able to understand the object of the Paper. It seemed, from the opening remarks, that it was intended to give information with respect to the mechanism, power, and operation of breaks for stopping the wheels of railway trains, but the instances which were given, related to the stopping of the trains themselves, by the friction between the wheels and the rails. Now if in the two cases cited, the trains were of equal weight, and the wheels to which the breaks were applied had equal weights upon them, then if the wheels were stopped in the same time by the application of either apparatus, the results must, of course, be precisely the same, although the mechanism of the one break might not only be more manageable, but vastly superior, in construction, durability, and economy, to that of the other. The results given in the Tables were, therefore, those which might have been arrived at, without any experiments whatever on the breaks in question; inasmuch as any apparatus used for stopping the wheels, would have produced exactly the same amount of friction, and would, therefore, have brought the train to rest, in exactly the same time and after running exactly the same distance. The

trains to which Mr. Fay's apparatus was applied, afforded a coefficient of 4·06, and those to which Mr. Newall's apparatus was applied, a coefficient of 4·10. Practically, there was no difference between the two sets of experiments, nor ought there to be; and the real question at issue was not, and could not be determined by experiments of this nature. The experiments simply showed, that the two descriptions of breaks were each capable of being applied to the wheels, with equal rapidity, and with sufficient force to arrest their revolving motion, but they left untouched the determination of their relative value, in an instrumental point of view.

With regard to the break applied as a dynamometer, it appeared, that under ordinary circumstances, the friction, or adhesion on a railway, deducible from these experiments, was about the same as had been generally received, since the time at which the Comte de Pambour wrote upon the subject; being about, on an average, one-seventh of the weight. In certain states of the weather, when the rails were wet and greasy, it was found to be as little as one-eighteenth to one-twentieth of the weight on the impeded wheels; and when the wheels were perfectly dry, as much as one-fourth, or one-fifth of that weight. All, therefore, that could be said as to the effect of breaks upon railway trains, was, that it must depend upon the velocity of the train, and upon the weight on the wheels to which the break was applied, as compared with the total weight of the train. Bearing in mind these two conditions; first, that if a train was suddenly stopped, it would greatly damage the carriages and, probably, injure the passengers; and secondly, that if the engine drivers had the means of employing a break which would stop a train within a very short distance, they would depend upon the use of that power, under all circumstances; it was probable, that instead of the number of accidents being diminished by a more powerful breaking apparatus, they would be greatly increased.

The formula to be used for the determination of the time and distance in which a heavy body could be stopped by friction, had been known and applied, ever since the law of gravitation had been discovered, and might be found in almost all books on mechanics. It was only necessary to know the pre-acquired velocity of the train, the total weight of the train, the weight insistent upon the sliding wheels, the gradient, and the materials of the sliding wheels and rails, to determine, within the limits of error due to the accidental condition of the rails, the distance and time at which the train would be brought to rest. From these considerations it appeared, that the Paper still left, in an undecided state, the relative merits, as mechanical appliances, of the two inventions.

Mr. VIGNOLES said, he could not concur in the opinion, that the

friction, or adhesion on a railway, averaged one-seventh of the weight of the train. For all practical purposes, he thought it was not to be taken at more than one-twelfth, in all states of the weather. That was a material point, because the friction, or adhesion of the engine upon the rails, was never, under the most favourable circumstances, one-fifth of its weight.

Captain Huish had seen Mr. Newall's break in operation some years ago, but he did not recollect ever having seen Mr. Fay's apparatus; the principle of both appeared, however, to be the same, and any future invention would, he supposed, be directed towards devising some method of locking all the wheels. There were two points for consideration; first, whether it was desirable to produce the effect proposed; and secondly, if desirable, whether in the conduct of a railway it could be carried into effect. He doubted whether this system of breaking could be efficiently maintained, even in a selected train, continuously used; and in any case, he did not believe, that railway companies would ever arrive at such an unanimity of opinion on the subject, as to cause it to be generally adopted. In the Report of Captain Galton,[1] it was was stated, that "the efficient action of such a system of breaks might be, to some extent, diminished by the mere adoption of the system, by all the companies whose carriages are used on the lines; but they would point out, that the cases are few in which, if the larger companies would adopt it for their own stock, careful management in working of the trains could not enable the system to be effectually applied." Now they might be few; but if throughout the kingdom, a single trunk line objected, there would be no possibility of effectively carrying out the plan, for the trains of the London and North Western Company came in, with the carriages of many other companies intermixed. Although the London and Brighton, and perhaps, the Eastern Counties Railways, with their tributary branches might, as isolated systems, carry into effect an arrangement of this kind, it was certain, that the general assent of all the companies would never be obtained, and unless all the carriages of every company were built for the purpose, the whole system was rendered ineffective. The strongest evidence against it was to be found in the fact, that although it had been constantly brought under notice by paragraphs in the public newspapers, yet the system did not extend. Even upon the Lancashire and Yorkshire Railway, where it was first introduced, he doubted whether it was considered in any other light than an experiment. He entirely concurred in the opinion, that by giving the guards such efficient machinery and perpetually calling it into action upon

[1] *Vide* "A Letter from the Railway Department, Board of Trade," September 27th, 1858.

all occasions, the vigilance of the persons in charge of the trains would be materially relaxed. The best break he had hitherto seen, for universal application, was Mr. M'Connell's steam break. A railway train consisted, upon an average, of about seven carriages, the average weight of which would be from 28 tons to 30 tons; including the passengers, it would not exceed 30 tons. The weight of the engines averaged about 30 tons; thus the momentum produced was equal to the entire weight of the train. The introduction of a steam break would place at the disposal of the engine driver, a power which could be brought into operation, whenever there was any imminent danger. The action of that break was very powerful; it certainly did injury to the rails, but it was only intended to be used in exceptional cases.

Mr. Hawkshaw, V.P., could not subscribe to the doctrine, that the more perfect the machinery, the more mischief was likely to arise in the application of it. This system of breaks had been tried, for some years, on the Lancashire and Yorkshire Railway, and it was admitted, that it could only be successfully applied to carriages which always ran together; it became useless when carriages belonging to other companies formed part of the train. These improvements, therefore, although ingenious, had not been generally applied on the Lancashire and Yorkshire Railway. He did not think there would be so much danger as was apprehended, in locking all the wheels of a train, for the stoppage would not be so sudden as to injure the passengers. The breaks now in general use, were good; the break vans were constructed so as to command a large amount of break power, and these vans, having an especial object, were likely to be properly attended to, and could be relied upon when wanted. The application of breaks to the locomotive engines, which had been recommended, was a very old expedient; the system was applied, twenty years ago, on lines near Bolton, but it was found to act so injuriously upon the engines, that the plan was abandoned. The value of a break was to be measured by its capability of locking the wheels of a train; and upon the quickness and facility with which this could be accomplished, depended the whole value of every system of breaks. The comparative merits of the two breaks mentioned in the Paper, consisted simply in the greater, or less facility of their application.

Mr. Hemans said, as there appeared to be some difficulty in discovering the object of the present Paper, he would, in the absence of the Author, venture an opinion. He thought it was intended to establish a general formula which would apply to the time and distance in which a break ought to stop a train, at all velocities, and on all inclines, up, or down; and that the break which produced an effect most nearly approaching that standard of comparison, was considered to be the most perfect. It was obvious,

that from the moment the wheels of a train became completely locked, the effect was precisely the same, whatever break had produced the result. The value of the break, therefore, consisted in the rapidity with which this could be accomplished. The formula gave the results that ought to be obtained; and that break which approached the nearest to it, from the instant of its being applied to the wheels, was to be considered the best.

Mr. HAWKSLEY said, there never had been any doubt as to the formulæ; they had been laid down in all the books upon the subject, long before railways were invented, and the conditions of the action of gravity and of resistance by friction, must remain the same for ever.

Mr. POLE inquired the results of the application of the continuous break, in use upon the North London Railway. He had understood, that one of the great advantages of the system, was, that it reduced the time required for frequent stoppages; and he presumed, that the expense of it on that line would supply evidence on the point.

Mr. WIGHTMAN replied, that he had only seen the break in operation, when the North London train ran into the station of which he had charge. He could not, therefore, give any exact details, but it appeared to be a continuous break, worked by a chain communicating with four carriages. He had observed, that the engine drivers of that company depended too much on the great power of the break, and although little danger was to be apprehended at intermediate stations, he feared some accident might, eventually, occur at the terminal stations.

Mr. CHAMBERS said, he had introduced the apparatus referred to, which had been in operation for two years on the North London Railway, and had never yet failed. The manager had declared, that without this break, the present accuracy of running could not be maintained on the line.

Mr. BATEMAN considered, that the chief object of the Paper was to institute a comparison between the break of Mr. Newall and that of Mr. Fay, rather than to treat, generally, of the principle of breaking. Having been a frequent passenger upon the East Lancashire Railway, where, for some years, Mr. Newall's break had been applied to some carriages, he had noticed, that the train was stopped in a very short time, and that the plan appeared to answer exceedingly well.

Mr. BROUGHTON was in the service of the East Lancashire Railway, some years ago, when Mr. Newall's break was first introduced. Since then, he had tried it upon the Ulster Line, where it was still in daily use. One advantage was, that it stopped a train much sooner than the break on the guard's van; and another advantage was, that the wheels were not skidded, and

there was a considerable diminution in the wear and tear of the rails, at the stations. He had also been informed by the superintendent of the locomotive department, that the tyres of the tender and carriage wheels now lasted longer than before this break was used. The experience of four, or five years had convinced him, that the advantages of the system were considerable.

Mr. Bidder,—President,—said, that if the object of the Paper was, as had been stated, to define the difference between Mr. Newall's break and that of Mr. Fay, it certainly had not pronounced in favour of the one, or the other. A decision of that kind was very difficult to arrive at, as there were so many elements to be taken into consideration; the state of the weather, the condition of the rails, and the condition of the breaks themselves. If, on the other hand, the object of the Paper was to establish a formula of the adhesion of metal to metal, that could be easily obtained from the simple rules already laid down, and must be well known to every one in charge of a railway. The adhesion varied, according to the state of the atmosphere, from 1 in 4 to 1 in 20; and the only question for those who had the control of the machinery, was to determine the amount of adhesion, under the circumstances most commonly met with in their experience. Whether the velocity was 30 feet, or 100 feet per second, if the resistance was 1 in 6, or 1 in 20, it would take six times, or twenty times the height required for a body to fall, to estimate the distance to bring the train into a state of rest; and the time required would be in proportion. But to propose a formula, was to go back to the most elementary proposition that could be submitted to a scientific institution. Experiments upon breaks, to be of any practical value, and to test their capabilities, ought to be made under circumstances of difficulty and intricacy. But after all, the practical solution of the question was in the commercial view of it; and if the Inspectors were paid by a per centage on the net earnings, with a corresponding deduction for the damages occasioned by accidents, the most efficient breaks would soon be provided.

One great object of breaks was the saving of time in stopping a train, particularly on short lines. Now the safety of the passengers being mainly dependent upon the engine driver, the greater control he had over the train the better, for he was, generally, in a position to see the first indication of danger. If he had to rely upon a self-acting apparatus, or upon apparatus under the control of others, he would not, as observation had proved, shut off the steam in approaching a station, whether intermediate, or terminal, so soon as he otherwise would do; and the safety of the public was thereby endangered. The break could not be applied to the engine, without injuring that most expensive element of railway machinery; and in a commercial country it could not be expected, that a rail-

way company would provide for the safety of the public, in a manner so greatly disproportionate to the commercial results. He thought, therefore, that all things considered, the most efficient break was that ordinarily in use.

This discussion recalled to his recollection, an anecdote which was somewhat *à propos* of the subject. A gentleman connected with the office of the late Mr. Robert Stephenson, but who had no scientific knowledge, had ascertained a formula for deciding upon the merits of breaks, which was more efficient than that given in the Paper. When inventors, each in their turn, insisted on laying their plans before him, he would inquire of them, the peculiar advantage of their particular breaks. "It will stop the train dead," said the inventor. "That will be the state of the passengers," retorted the other. "But it will also stop a train gradually." "So will the break of anybody else," was the conclusion at which the unscientific gentleman had arrived.

April 24, 1860.

GEORGE PARKER BIDDER, President, in the Chair.

No. 1,019.—"Account of the Works recently constructed upon the River Severn, at the Upper Lode, near Tewkesbury." By EDWARD LEADER WILLIAMS, M. Inst. C.E.

THE whole of the works constructed, during the past fifteen years, for the improvement of the navigation of the River Severn, between Stourport and Gloucester, were projected in 1841, by Sir William Cubitt, (Past-President Inst. C.E.). The impediments at that time existing to the navigation of the river, in the district in question, were of two kinds. Those in the upper portion, between Stourport and Tewkesbury, consisted of beds of marl rock and compact gravel, which intersected the channel at various points, causing shallow rapids at low water; but acting also as natural dams, they penned up the water in the intermediate deep reaches. The other class of impediments consisted of shoals of quicksand and mud, deposited by the winter floods and the spring tides, in the lower district, between Tewkesbury and Gloucester, wherever a sudden increase of width in the river channel gave an enlarged sectional area, and caused a corresponding decrease in the velocity of the current. The distance between Stourport and Diglis, near Worcester, is fourteen miles, and the fall per mile, at low water, in 1841, was 19·75 inches. From Diglis to Tewkesbury, sixteen miles, the fall, at low water, was 4·70 inches per mile, whilst the fall in the ten miles between Tewkesbury and the Upper Parting, near Gloucester, is only 2 inches per mile.

The scheme of improvement laid down by Sir William Cubitt, in 1841, was that indicated by the natural features of each district. In the upper portion of the river, the natural dams were to be removed by dredging, artificial weirs being substituted, with corresponding locks, in side cuttings, for the passage of the traffic. In the lower district, the tendency to deposit was to be counteracted, by the construction of fascine embankments running parallel to the course of the current, and equalising the sectional area of the channel; the accumulations of sand being, in the meantime, taken up by steam dredgers, and deposited behind the fascine embankments. The proposed sites for the locks and weirs

were Lincomb near Stourport, Holt, Bevere, Diglis, near Worcester, and Ryall, between Upton and Tewkesbury.

The intended application of artificial works to so important a river as the Severn, whose floods have been known to rise 18 feet in five hours, and, not unfrequently, to attain a height of 25 feet above the level of low water, naturally excited much discussion, especially amongst the owners of land upon the river banks, and these discussions led to a very searching and protracted Parliamentary investigation into the merits of the scheme of improvement. The result was the appointment of a body of Commissioners, to whom power was delegated to execute the whole of the projected works, with the exception of the lock and weir at Ryall, which was to be abandoned, and in its stead, an attempt was to be made to improve the navigation of that portion of the river, between Diglis and Ryall, by dredging through the extensive beds of gravel and marl, which intersected the channel at several points in that district. This decision was arrived at, in opposition to the evidence given upon the part of the promoters, to the effect, that the removal of the natural dams, without the substitution of an artificial weir, would lower the surface, instead of increasing the navigable depth.

Papers giving a full description of the works erected between Stourport and Diglis, together with the blasting of the red sandstone, and marl rocks, under water, and the dredging operations, have been already presented to the Institution;[1] these portions of the work, therefore, require no further notice. It must, however, be stated, that the result of the experiment, forced by Parliament upon the promoters of the improvements, was, that after having kept four steam dredgers constantly at work for upwards of two years, and having removed more than 1,000,000 tons of marl, gravel, &c., it was found, that the level of low water upon the lower cill of Diglis Lock was lowered 3 feet below its original mark, and that the required navigable depth could not be maintained. This state of things obliged the Severn Commissioners to renew their application to Parliament, for powers to carry out Sir William Cubitt's original plan in its integrity, with a slight alteration in the position of the proposed lower lock. This alteration was suggested, to meet the local requirements of the town of Tewkesbury, the site of the projected works being removed from Ryall, four miles above that town, to the Upper Lode, half a mile below it. A fierce, and protracted, Parliamentary struggle, extending over five years, resulted, in 1852, in the ultimate triumph of the projectors; but the unfavourable state of the money market delayed the execution of the works, and it was not until the autumn of 1856, that they were commenced.

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. iv., p. 361; and vol. v., p. 340.

The channel of the Severn at the Upper Lode, formed, at that time, an acute angle, changing from N.W. to S.S.E. This sudden bend interfered prejudicially with the navigation, as well as with the discharge of the flood waters; it was, therefore, determined to construct the proposed works in new channels, with easy curves, and to cut off the objectionable angle. The course of the river, both in its unimproved, and its improved state, is shown in Plate 5, Fig. 1. Twelve years' practical working of the locks and weirs between Diglis and Stourport, had demonstrated the correctness of the principles upon which they had been constructed, and little in the shape of improvement remained to be effected, in the details of the works at the Upper Lode. The introduction, upon the river, of steam power for towing, had, however, proved, that much time could be saved by an arrangement that would admit of the passage, at one locking, of a steam tug, with an accompanying fleet of vessels. It was, therefore, determined to effect this object by adding a basin, or second chamber, to the lock proper, which basin should be entered by a pair of gates, similar in every respect, to those of the lock, the line of the bottom of both lock and basin being uniform throughout, and therefore, by working the upper gates of the lock with the lower gates of the basin, the whole intervening space would form a large lock chamber. The lock proper is 120 feet in length and 34 feet in width, and the basin is 156 feet in length by 80 feet in width; the total length between the upper gates of the lock, and the lower gates of the basin, being 276 feet, and the enclosed space, sufficient to lock up a steam tug, together with six Severn trows, each of 100 tons burthen. A plan and longitudinal section of the lock and basin are given in Figs. 5 and 6; and transverse sections, in Figs. 2, 3, 7, and 8.

The depth of excavation required for the lock pit, was 35 feet, and here some difficulty was anticipated, as the trial pits gave the following section. There were 2 feet of loam beneath the grass surface, 16 feet of sound red brick clay, 14 feet of imperfect blue lias clay intermixed with black mud and decayed vegetable matter, in which strong springs of water were met with, and 4 feet of compact blue lias clay, overlying a thick bed of water-bearing gravel. The sides of the first 18 feet of excavation stood at a batter of 1 to 1, and no difficulty was experienced, until the 14-feet stratum of imperfect blue clay and black mud was reached, but no sooner was the sound upper crust removed, than the semi-fluid mass beneath it began to rise in the pit, letting down the clay on each side, and breaking up the whole into a confused mass. The remedy first suggested, was to drain off the water by powerful pumps, but the proximity of the river, which surrounded the work on three of its sides, gave little prospect of success from such an attempt. Relief was, therefore, sought in another, and as experience

proved, the right direction. Finding that it would be useless to attempt to encounter the whole mass at once, it was determined to attack it in detail, and a pit, 20 feet long and 12 feet wide, was commenced in the line of the proposed east wing wall of the lock forebay. As the excavation of this pit proceeded, its sides and ends were planked with half timbers, well strutted; but notwithstanding every precaution, much anxiety was felt, as the pressure of the surrounding mass was so great, as frequently to cause whole timber struts to give way. As soon as the sound clay was reached, the pit was filled with concrete, the timbers being removed as the filling proceeded. A second pit, of similar dimensions to the first, was then commenced at a distance of 20 feet from it, in the intended line of the lock wall, the intermediate space of soil being left in, until the concrete in the first pit had become consolidated. This process was continued throughout the whole length of the excavation, on each side, and by the time it was completed, the concrete in the pits first filled was sufficiently firm, to admit of the excavation of the remaining spaces of 20 feet between them.

The whole of the wall foundations, composed of concrete 12 feet in width, and 14 feet in depth, were thus got in. It was expected, that this large mass would, by its gravity, sufficiently resist the pressure of the soft soil by which it was backed, especially as the blue clay, in the centre between the two lines of concrete, was left in; but this expectation was not realised, as the pressure proved to be sufficient to force the two concrete walls bodily inwards, to the extent of 18 inches on each side, and to press up the intervening blue clay, until its surface assumed the appearance of a troubled sea. Strutting timbers of large scantling were then fixed, to prevent the further inward movement of the side foundations, whilst transverse pits were sunk between them, and were filled in with concrete, forming an inverted arch, 6 feet thick at the crown. These pits were gradually carried through the whole length of the work, upon the same plan of operation as had been adopted in the side wall foundations. The sinking of the first of these transverse pits, however, demonstrated, that something more efficient than struts of whole timber was required, to prevent the inward movement of the sides. The balks gradually sprung, until it was evident, that they were unequal to their work, and that before the bottom could be reached, they would give way. To meet this new difficulty, pits were sunk at the back of the longitudinal walls of concrete, at right angles to them, running 10 feet into the slipping mass of clay at the back. These pits were 10 feet wide, and were sunk to a depth of 2 feet below the bottom of the concrete wall foundations, in order that the bottom line of the whole mass should not be uniform. The concrete filled into these pits, formed counterforts to the lock wall foundations, and they were carried 12 feet

apart, through the whole length of the work, at the back of each side wall. This arrangement very much reduced the movement, but it was not quite overcome, until the inverted arch of concrete, which formed the centre, was completed. The pressure in some of the transverse pits was so great, as to render it unsafe to remove the whole timber struts, and in these cases, they were left in the pit, and buried in the concrete. The concrete foundations thus completed, contain upwards of 7,500 cubic yards, and upon them the lock walls are built.

The lock chamber, invert, and wing walls, together with the walls of the lower entrance to the basin, are faced with blue Staffordshire bricks, and are backed with bricks made from the upper stratum of red clay. The walls of the basin are built of rubble stone from the neighbourhood of Chepstow, set at a batter of ½ to 1 upon the face. The quoins and copings are of grey sandstone, from the Forest of Dean. The cills, into which shutting cills of elm timber are firmly bolted, are of red sandstone, from Areley, in Shropshire. The lock gate-frames are of oak, and they are planked diagonally with pitch-pine planks; they are worked by balance beams of cast iron. The upper gates of the lock are 25 feet high, and 20 feet 6 inches wide; the two pairs of lower gates are 33 feet high, with the same width as the upper gates, and being carried upon an iron pivot, with a hemispherical steel top, are easily worked by one man. The lock and basin are filled and emptied, by means of culverts, 6 feet high and 4 feet wide, in each of the side walls, and the whole area contained between the upper gates of the lock and the lower gates of the basin, is filled through these culverts, in five minutes. The paddles, with their lifting gear, are similar in construction to those of the Upper Severn locks, which have been described in the Paper already alluded to; they will, therefore, require no further description.

The weir, of which transverse sections are given in Figs. 4 and 9, is 500 feet long, 40 feet wide, and 6 feet high. A row of close piling at the foot of the inclined apron forms the lower cill, the upper cap cill being laid upon walings of half timbers, which are bolted to gauge piles, driven 12 feet apart through the whole length of the weir. The space between the two cills is filled with rubble limestone from Chepstow, and the face of the apron and back of the upper row of piling is pitched with the same description of stone, set in courses, and rough-pitched upon the face. The section of the back pitching is a parabolic curve, which is continued over the cap cill; experiments tried upon the Upper Severn weirs having proved, that this form facilitates the discharge of the water, instead of causing that upheaving of its surface at the line of contact, which is common to weir cills of other forms. The apron inclines at an angle of 1 to 5 down to the

lower cill, beyond which, a horizontal stone sheeting, similar in construction to the apron, extends to the width of 10 feet, and protects the lower row of sheet piles from the scour to which they would otherwise be exposed. The east end of the apron is considerably curved, in order to admit of its extension at that point, and to ease its inclination of 5 to 1, to 10 to 1; the object being to facilitate the passage of the salmon up the river, which is further promoted by a groove 4 feet wide, and 12 inches deep, formed in the face of the inclined plane, in the centre of the curve before alluded to. The effect of this arrangement is to secure a sufficient depth of water always passing down the groove, to cover the back fin of the fish, and thus they are enabled to pass up the river, without hindrance, even in seasons of drought. The heavy freshes to which the Severn is subject, are discharged by the weir with such rapidity, as to fill the channel of the river below it, five times as fast as that above it is filled, until the surface forms one unbroken plane, by the weir being thrown out of operation. Thus a rise of 1 foot 6 inches in the upper level, causes a rise of 7 feet 6 inches in the lower level, at which height the weir is out of action.

The lock and weir being completed, the old channel of the Severn was dammed up, at a point indicated upon the plan, (Fig. 1,) where the width of the channel was 60 yards. The dam was carried across the river, and the water raised to the height at which it would flow over the upper cill of the weir, by a simple process. A jetty, formed of thorn kids, or fascines,—each kid, or bundle, being about 6 feet long and 15 inches in diameter,—was commenced on each side of the river, and after the abutment of each jetty was well punned, with stiff clay, into the opposite banks, the work was advanced from each side, at an angle of $22\frac{1}{2}°$ pointing up the stream, the kids being laid in courses three deep, and the brush end of each course being advanced a head, 12 inches beyond that upon which it was laid. After the three courses were got in, they were covered, and weighted, with stiff clay, which was well trod into the thorns, and upon this bed, three other courses of kids were laid as before, the work advancing, both a head, and in depth, as the process was continued. As the heads of the advancing jetties approached each other, reducing the open space between them, the rush of water through it was like a mill race; but notwithstanding the continued increase of the velocity, due to the increasing head of the upper level, the brush ends of the kids were advanced without the slightest interruption, or difficulty, until both jetties met and formed the base of the permanent dam. This was, ultimately, increased to a width of 130 feet, and the towing path was carried over it, banked up, above the flood level.

The estimated cost of the whole of the works which have been described, was £35,000, and although the contingencies were unusually heavy, the expenditure has been within the estimate. They have stood the test of the floods of last winter, without damage, and have demonstrated the correctness of the principles originally laid down by Sir William Cubitt, for the improvement of the navigation of the River Severn.

The tugs used upon the river are paddle-wheel boats, 93 feet long by 19 feet 6 inches over all. They are worked by side-lever condensing engines, with cylinders 30 inches in diameter, and a stroke of 4 feet. The boilers have three furnaces with ninety return tubes, each being 5 feet 9 inches in length, and $2\frac{1}{2}$ inches in diameter; the steam is worked to 20 lbs. per square inch. One of these boats sometimes brings up, from Gloucester to Worcester, a string of twelve loaded Severn vessels behind it; the dead weight, hauled at the rate of three miles per hour, against the stream, being upwards of 700 tons.

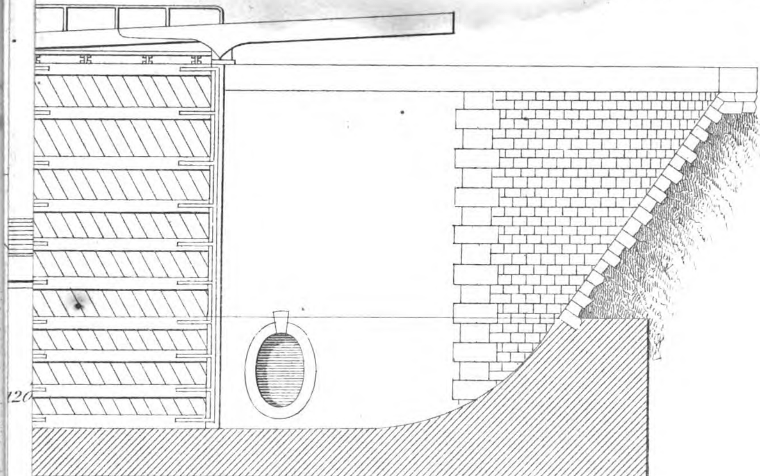
The Paper is illustrated by plans and diagrams, from which Plate 5, (Figs. 1 to 9,) has been compiled.

[Mr. W. A. Brooks

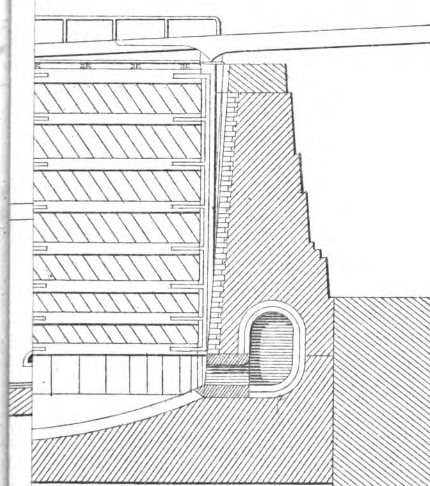
Mr. W. A. Brooks had great respect for any work designed by Sir William Cubitt, but not being acquainted with the locality, he could not pronounce an opinion, without further examination of the plans, and a knowledge of the state of the river. He was opposed, as a general principle, to placing weirs across navigable rivers, and he was, therefore, not convinced, that the present experiment would be successful. He wished to know the state of the navigation below this weir, which had occasioned, it appeared, a loss of tidal range of about 6 feet. He thought the navigation below must suffer, although it would, no doubt, be alleged, that the upper navigation of the Severn was mainly due to the power of the land floods; and, therefore, that the tidal scour was not so essential as in other cases. In the Severn, the floods rose to an enormous height; and this, probably, contributed to maintain the channels. But a better effect would have been produced upon the navigation below, if the full tidal flow had been preserved. If any recent soundings had been taken of that part of the navigation, it would be desirable, that they should be laid before the Institution.

Mr. John Murray had been much pleased with the Paper, which gave a very detailed account of a difficult work,—getting in foundations, so near to, and nearly surrounded by, a large body of water. The Author had treated the case very effectually, by executing the work in patches, and leaving the natural surface of the ground untouched, until he had secured the portion upon which he was immediately engaged. By raising this dam, the upward flow of the tide would, no doubt, be obstructed, and the scour be thereby lost; but on the other hand, the weir improved the navigation in the upper part of the river, for without it there would have been very little depth of water. To keep up the navigation, the weir must be maintained and the river improved below, to compensate for the exclusion of the tidal water. The river should not be allowed to remain in its present state, but improvements should be made in the bed below, to keep pace with the other works, carried on in the upper part of the stream.

Mr. Beardmore was not well acquainted with this part of the Severn, but he admired the third pair of gates and the large basin, below the lock, because it was the only method he saw of accomplishing the object of transporting trains of barges, towed by steam power, by which means alone competition could be maintained with railways, especially in the carriage, for long distances, of great quantities of merchandise, at comparatively slow speeds. He had recommended a similar plan, for a river in which vessels of large tonnage were employed, where the third pair of gates and head of the basin had to be constructed, without stopping the traffic through the lock above. The Author of the Paper had



TION OF BASIN



TION OF LOCK

KELL BROS LITHRS CASTLE ST HOLBORN.

demonstrated a plain fact, worth more than whole days of evidence before a Parliamentary Committee, that although the water was penned-up 5 feet at the weir itself, yet the effect of giving a large mean depth, and bringing the water over the weir by a good section and ample weir pool, resulted in the floods being carried over the weir with less heading above, in the proportion of 1 to 3, compared with the 'tailing-up' of the natural river below. This was to be attributed to enlarging the body of water, to increasing the hydraulic mean depth, to removing the shoals, and to "regulating the section of the river.

When a river, from its natural position and character, required canalisation, the most convenient method to pursue, was to make a weir and to combine it with the requisite increase of depth; but, of course, at the lower, or tidal, end of a river, there must always be a point, at which dredging and a freer admission of tide, became more desirable and was also less costly. Increase of the hydraulic mean depth, however, was not less remarkably advantageous in the latter case; being the most perfect way of conveying a volume of water, and of maintaining a deep channel where there was a deficiency of fall, either in the continuous downward flow of an upland river, or the oscillating flow of a tidal estuary. He considered this to be one of the golden rules in works for navigation, for drainage and other hydraulic operations, as well as in the treatment of tidal channels. He did not now propose to enter into the question, whether the weir and lock, under consideration, were placed at the proper point, with regard to the tidal action of the Lower Severn; that was a purely local and practical question, and one on which the Author of the Paper must be the most competent authority. That the increase of sectional area and an efficient hydraulic mean depth, combined with a judicious application of weirs, would benefit the flood-discharging power of the River Severn, was the great matter of debate in the early history of these improvements; he would, therefore, ask whether the lands were now better drained, and whether the water stood higher, or lower, at flood time, than formerly.

Mr. J. Cockburn Curtis, during the Parliamentary contest alluded to by the Author, was called upon, in 1848, by the Admiralty, to examine and report upon the question of erecting the weir and locks which had been described in the Paper.

There was one point regarding the treatment of rivers, which had been touched upon, to which he would call attention. It had been correctly stated, that whenever it was wished to increase the facilities of navigation in a river subject to droughts, the great point was to increase its hydraulic mean depth. He concurred in this general principle, but he contended, that with the same

amount of water passing down a channel, it was possible to increase the hydraulic mean depth, by three different processes; first, by the erection of a weir and penning back the water, as described in the Paper; secondly, by excavating the head of the channel to a sufficient depth so as to reduce the slope; and thirdly, by embanking the channel at the sides so as to reduce its width. The determination of which of these modes of treatment should be adopted, must be dependent upon the character of the supply of water from the catchwater basin, and the configuration of the valley and channel of the river, in the district under consideration.

He could not concur in the sweeping denunciations which were sometimes made against the use of weirs in the improvement of rivers, for his experience and examination of river works in India and Spain had convinced him, that in many cases, the physical disadvantages of rivers might be overcome, and both the navigation and the drainage might be materially benefited by their erection. In districts where the inclination of the river bed and the slopes of the adjacent valley were considerable, and when the natural channel above the weir was much encumbered by shoals, if the weir was constructed of sufficient length, it would, generally, be found, that the ordinary summer supply, and the first freshes and floods would pass down the portion of the river in which the weir was placed, with considerably more velocity than they did before it was erected. This result was to be attributed to the shoals which formerly obstructed the stream at its lower levels, being covered by the water penned back by the weir, so that the ordinary drainage and the first freshes and floods, coming in the earlier stages of their progress, into a channel pre-occupied by water, experienced less resistance to their passage than they did previously, when they had to contend with an almost empty channel impeded by shoals. He confined, however, these observations, as to the effect of a weir, to the lower levels of the river, and to the early stages of the freshes and floods; when the water accumulated below the weir, and the weir became 'drowned,' or thrown out of action, it then acted simply as a steep shoal, or ford, in the bed of the river, and, as such, no doubt, created an obstruction to the final passing off of the flood waters.

During his examination in 1848, he had a series of observations made at two stations, one, half a mile above, and the other, half a mile below the weir, at Diglis; and he found, that at the lower levels, the discharging power of the channel above the weir, even exceeded that stated by the Author. These observations showed, that when there were only 3 inches, or 4 inches passing over the weir, the channel above the weir discharged the water eight times faster, than the channel below it could carry it off. But this pro-

portionate rapidity of discharge decreased very rapidly as the water rose in the lower, or natural channel, and eventually, as the slope of its surface and the hydraulic mean depth increased, the natural channel had the advantage as regarded rapidity of discharge. He considered these results attributable to the relative existence, or absence of friction; in short, to the fact, that water could pass over water much more easily than it could over stones, or gravel.

The fall of the River Severn between Stourport and Diglis, before the weirs were erected, was about 21 inches per mile, while the natural fall between Diglis and the site of the Tewkesbury weir was about 4½ inches per mile, or about one-fifth of the natural fall of the upper district; the valley of the lower district was also considerably broader. Before the Tewkesbury weir was erected, spring tides, occasionally, rose as much as 18 inches at Diglis, and 4 feet at the site of the Tewkesbury weir. Looking at the marked difference in the character and configuration of the upper and lower districts, he had come to the conclusion, that the system of improvement by weirs, would be attended with great disadvantages, if extended below Diglis; but at the same time, he freely admitted, that much might be said on the other side of the question. It appeared to him, that from the much greater extent of district to which the level of the penned water would extend, at the lower levels of the river, and the circumstance of its being so much sooner thrown out of action, by the banking up of the tail water, or the rise of spring tides, it could not but have an injurious effect on the drainage of the valley lands; that if the weir was made sufficiently long for the discharge of the flood waters, it would have a tendency to drain off the summer water too rapidly, and thus to diminish the summer supply for navigation in the channel below it; and that cutting off 16 miles of the tidal flow of the river during spring tides, could not but have a prejudicial effect upon it and its estuary. He thought, therefore, that all these objectionable results might have been avoided and the opposite advantages been attained, if the head of the channel between Diglis and Clevelode, had been originally deepened to such an extent as to lessen the slope of the channel, and thus to retain the water in it during the times of drought; while the deeper channel which the river would have thus afforded for the passage of the heavy floods, would have allowed their full and continuous energy to have been subservient to the maintenance and deepening of the bed of the river.

In the absence of plans and sections, and of hydraulic observations of the present condition of the river and its estuary, it would be impossible for him to state, how far the conclusion at which he

had then arrived, was borne out by the facts of the case. A careful survey of the physical condition of the river had been made by the late Admiral Beechey, prior to the erection of the weir, and if similar information existed of the present state of the river, it would have been instructive to have compared the results which had actually ensued, with the opinions expressed by the different Engineers who had previously discussed the question.

Mr. Parkes had paid some attention to this subject, at the time this weir and lock were in contemplation, and he confessed he had arrived at the conclusion previously expressed in the discussion, that the portion of the river between Worcester and Tewkesbury ought to have been differently treated. He thought, however, it was not very important, whether the weir was placed there, or not; but the assertion, that the river could not have been improved by the more natural system of regulating its width and depth, should not be allowed to pass without protest. The Severn, between Worcester and Tewkesbury, consisted of a series of deep reaches, which lay diagonally along the valley of the Severn. The river at the ends of these deep reaches struck upon the sides of the hills on either side, and there, coming upon hard ground, the channel of the river was shallow, and the stream ran with considerable velocity. He believed, that almost the whole of the fall between Tewkesbury and Worcester occurred in these shallow places, against the sides of the valley; and at the time that Parliament decided against a weir below Diglis, near Worcester, an attempt was made to deepen these places, so as to give the depth of 6 feet, which was assumed to be required. He thought that operation had not been performed in such a manner as was likely to be successful; for it appeared, that although the channel of the river at the summer level was increased, yet nothing had been done to diminish it in those parts of the section which were only covered during floods, when the channel was subject to the greatest scour. The consequence was, that the places which had been excavated, were filled up when the floods came down, and when the sectional area was larger than before the improvements were effected. But there was another operation which ought to have been carried on, simultaneously with enlarging the channel in the shoal parts. The deep-water reaches between these natural weirs had no fall whatever; the channel, therefore, ought to have been contracted so as to increase the inclination and to raise the surface of the water, at the lower end of the shoal next above. There might then have been a less inclination over the shoals, than previously existed, without the level of the water at the head of the shoals being lowered. The same process might have been carried on in all the reaches, so as to raise the water

1 foot, or 2 feet at the bottom of the next shoal, which might then have been deepened, without lowering the water at the head. By these means, the level of the surface of the water would have been maintained at Worcester. The depression of the water at this place, was thus owing to the deepenings having been executed without a corresponding raising of the parts which were unnecessarily deep: had the river been regulated instead of merely deepened, the failure would not have occurred. With regard to the works at, and above Worcester,—he had not seen those at Tewkesbury,—he could bear his testimony to their good effects, in improving the navigation and passing off the floods very rapidly. Complaints had even been made, that the floods were carried off too quickly, so that there was not sufficient water for the navigation, in the parts of the river above the influence of the weirs. That, however, was not a fault, as the object of the works was to carry off the floods quickly, and that result had, certainly, been attained.

Mr. M. Scott was anxious to hear from the Author, the principle on which he was led to adopt that peculiar curve for the profile of the weir.

Mr. Hawksley was acquainted with the River Severn, and having lived for many years upon the banks of the Trent, where these weirs were first introduced by Mr. Jessopp, so far back as the year 1780, he had ample opportunity of observing their effects. Oblique weirs were not, usually, of any great benefit, but under ordinary conditions, they delivered the water with a lower depth over the top than straight weirs, and so far, they might be said to be serviceable. That was an effect, however, which it was not always desirable to obtain, and in these cases, an oblique weir was less beneficial than a straight one. The change effected in the tidal action by placing a weir across a river, was, in general, detrimental; not seriously so, perhaps, in the lower part of the river, but only in the part near the weir itself. In the case of the Severn, he did not think any great evil had resulted, or was likely to result, from the weir, because the floods were so great, that they had a scouring effect quite equal to the daily tidal action, which the weir would interrupt. There was a point, however, in every river, and there was one in the Severn, where the effect of a flood became exactly equal to that of the ordinary tidal action. It would occur at a certain distance below the weir, and at that particular point a certain amount of deposit would take place, which would require to be removed by dredging. That point, in the case of the Severn, would not be within 10 miles, or 12 miles of the weir. But there was another circumstance to which attention must be drawn; the liability of the channel above the weir to become gradually filled up, in rivers with small slope, such as the Severn.

Whether that effect would result in the upper part of the Severn, must depend upon the floods producing sufficient scour to cleanse out the basins formed by the weir; if they did not, the channel would, infallibly, be gradually filled up. Another fact had escaped observation, the effect of a weir upon the adjacent lands. It would not be contested, that any obstruction placed in a river must have the effect of elevating the surface, in a greater, or less degree, according to circumstances. In the case of a weir like the one under consideration, the increased elevation above the top of the weir during floods, would, perhaps, not be considerable; but nevertheless, low-lying lands to which the water did not, formerly, reach in a flood of given magnitude, would be liable to be submerged, after the weir was established. The Severn was, fortunately, a river in which a weir of that kind could be placed without much injury, for the banks were, generally, high and precipitous. Although some portion of the valley was flooded during heavy rains, yet, considering the extent of country drained by the river, it was not a large proportion of the whole. In the Trent, in consequence of the elevation of the weirs, the water had overflowed the land, covering it for many miles, and to the extent of many thousand acres at a time. Whether in this case, the advantages accruing to the navigation did not counterbalance the damage to which the country had been liable, he did not pretend to say; that was a question which Parliament must determine. But as he had heard it asserted, that works of this kind did not have the effect of elevating the surface of the water, against this doctrine, he protested, both in a practical and in a scientific point of view.

Mr. Hemans remarked, that a number of weirs erected on the Shannon, had had the effect of raising the general level of the water in floods.

Mr. J. Cockburn Curtis stated, that the oblique weirs had been known in India and Spain for a long period; it was probable there were some in the former country, which were as much as two thousand years old. Under certain conditions, weirs of this kind possessed great advantages over those placed at right angles to the direction of the stream. He did not think it a necessary consequence, that an oblique weir would have the effect of raising the bed of the river on which it was placed; on the contrary, there was every reason to suppose, that some of the rivers on which they had been used, had not materially altered the level of their beds, for centuries.

Mr. E. L. Williams observed, that great importance had been attached to the construction of weirs in a tidal river, in such a position as not to interfere with the tidal flow; that the lowest weir should, therefore, be above the point reached by the tide.

But the Severn was peculiar in many of its features, and one of those peculiarities was its tidal flow. High water of spring tides in the Severn, extended forty-five miles beyond high water of neap tides. It became, therefore, a question of considerable importance to decide upon the position of the lowest weir, and how far it was desirable to carry out the canalising principle which had been adopted; and that question was discussed and tenaciously fought, in the Parliamentary Committees. The argument against the weirs was, that they would abstract from the flow of spring tides, a certain volume of water necessary for the scouring of the lower channel. This was met by the consideration, that at Tewkesbury, there was no tide at neaps, but only at springs, and as there was a great depth of water in the river above Worcester, by canalising at Tewkesbury, the flow of the floods would be facilitated, and by their more rapid discharge, a greater scouring of the lower channel would be produced. The character of the river altered at Tewkesbury so completely, that nature pointed out that spot, as the proper position for the lowest weir; for above Tewkesbury almost all the shoals were hard marl, or gravel which resisted the scouring of the floods, whereas the whole of the shoals below that place, with one, or two exceptions, were shoals of deposit, caused by the too great sectional area of the channel, in times of flood. Nothing, therefore, had been abstracted from the tidal flow of the river, whilst the passage of the flood water had been facilitated, through the district canalised. The water was discharged with so much rapidity, that the energy of the scour in the lower district, was more efficient than it was before the construction of these weirs. He was once asked by a Past-President of the Institution, who was standing near one of the Severn weirs, how the passage of the floods could be facilitated by construction, which had required the sinking of 7,000 tons of stone in the channel of the river. He admitted the result, but he could not account for it. The theory which Mr. Williams proposed was, that previous to the erection of the weirs, when the first fresh came down the channel of the river, it met with a series of impediments in the shape of fords, extending from 100 yards to 1,000 yards in length, which, of themselves, acted as natural dams in the river, and offered sufficient resistance to materially reduce the velocity; whereas a fresh coming into the district which had been brought under the regulation of these works, found, instead of a river comparatively empty of water, a series of deep quiescent pools, having, as had been correctly stated, greater hydraulic mean depth. The result of every year's experience had established the fact, that the discharge of the floods was due to the increased hydraulic mean depth; they ran faster through water,

than over gravel. The flood, instead of having to drag its way over gravel shoals, now came into deep water; the whole mass was put in motion, and the discharge was so rapid, at the large weirs, that no obstruction was offered to the current above. An idea, held by many opponents to the original plan of improvement was, that the construction of the weirs would facilitate the deposit of silt above them, and that the weirs themselves would silt up to the level of the upper cills, thus forming an inclined plane above, and gradually causing the river to fill up. But experience had proved the contrary. On comparing the original section of the river, made in 1842, before the weirs were erected, with a series of transverse soundings taken at 16 feet from the head of the weir, it was found, that the depth of the channel had been actually increased 3 feet to 5 feet. On taking longitudinal soundings, one mile and a half up the river, it was again found, that the depth had been increased the whole distance, 3 feet to 5 feet. The same effect had been produced in the whole of the pools between the weirs; the channel, indeed, was deepened to such an extent, that the banks which had stood for many years previously, had, in some places, fallen in, from the increased energy of the current having scoured out the bottom. Except where there was a sudden bend, there was seldom a deposit above the weirs. Below the lowest weir, the mode of improvement adopted, was to equalise the sectional area; and the consequence had been, that the increased velocity of the floods had tended to maintain the navigable depth more effectively, than before the construction of the weirs. The probable flooding of the low lands was a point insisted upon, before the Committee of 1842, and it was also the reason why the lowest weir was, at that time, abandoned. The Committee, having given power to construct four of the weirs, resolved to see the effect produced by them, before they would consent to place a long flat valley, 16 miles in length, under the same régime. But the effect above was so satisfactory to the landowners, that they willingly gave evidence in favour of the prosecution of the plan; for the floods were not only discharged with greater velocity, but they did not rise so high upon the land. It had been objected, that a weir could not be placed in the river without raising the surface of the water. Now one of the objects aimed at, was precisely to raise the low-water surface for the purposes of the navigation; another was, to construct the weir in such a manner as to facilitate the passage of the floods, so that whilst it improved the navigation, it should not prejudice the drainage of the low lands. To effect this, it was necessary, in the first place, to ascertain, by cross sections of the valley in all directions, the relative level of the low lands, as compared with the height of the water when penned-up, as proposed. When it

was found, that the height would not prejudice the drainage, the landowners were satisfied. It was now no longer matter of theory, but of fact, that the lands had been improved, and there was not a proprietor in Worcester, or Tewkesbury, who would not acknowledge it. It had also been objected, that the proper mode of improvement had not been adopted below Diglis, that instead of establishing a weir, the sectional area in the long reaches should have been equalised, the impediments being confined to some obstructions of marl, or gravel, in the bed of the river. Now, he thought Nature was the best instructor, and that those deep reaches taught Engineers the direction in which they should proceed. For instance, there was one reach of the Severn above Tewkesbury, 4 miles in length, with a section as defined as that of any canal, not varying for each half-mile, more than a few feet. Three of the cross sections, indeed, were so close, that they would scarcely be imagined to be those of a river which carried such floods as the Severn; they did not vary more than 13 feet, or 14 feet in 1,300 feet, or 1,400 feet of section. Nature, then, having pointed out the width at which a sufficient navigable depth could be maintained, instead of interfering with that section, it was taken as the best guide for the efficient drainage of the flood water, and the maintenance of the navigation. The sectional area of the channel was increased, thus creating an hydraulic mean depth equivalent to that of the reach alluded to, and a weir was constructed to discharge the water as fast as it came down. He was satisfied that was the right course, and the landowners and others who were originally opposed to placing a weir near Tewkesbury, now thought it the best part of the whole work. The Earl of Coventry and Sir Edmund Lechmere, both being landowners in that district, had confessed, that their land was considerably improved by these works. He had been asked why a parabolic curve was adopted at the back of the weir, and why it was supposed to discharge the water more rapidly than any other form. He was led to adopt it, in consequence of experiments made in a trough of water, with floats placed at different distances from the bottom. Observing that with an oblique weir, the floats, as they simultaneously approached it, all described a parabola, that curve was given to one of the upper weirs, which was then found to discharge, at a head of 9 inches, as much water as a weir four miles above, of the same length, but with an inclined backing, at a head of 12 inches. In the one case, there was an upheaving of the water as it approached the edge of the cill; in the other case, the flow was uniform. He would give a striking illustration, which admitted of no dispute, that a weir could be placed in a river, without interfering in any way with the action of the under-current below the cill. Nearly

twenty years previous to the construction of the Severn works, a vessel had sunk, about four miles above Worcester, in a deep part of the navigable channel; but as it offered no obstruction to the navigation, it had been allowed to remain, and had become half filled with sand. The first fresh which came down the river, after the erection of the Severn weirs, removed the old vessel and deposited it upon an island, a little above the next weir. During a trip up the river, he related the circumstance to Sir William Cubitt, to the late Mr. Brunel, and to Mr. George Edwards, who had superintended the dredging operations for Messrs. Grissell and Peto. Mr. Edwards then mentioned, that he had deposited, whilst the works were in progress, about 100 tons, or 150 tons of gravel boulders in the channel, at Holt, between the entrance of the navigable cut approaching the lock, and the weir. The man who deposited these boulders happened to be employed, when this conversation occurred, as assistant lock-keeper at Holt, and on the party arriving there, he was instructed to sound the channel at the place of deposit, when it was found to be perfectly clear, all the boulders having been carried away. That was within 100 yards of the head of the weir, and similar results had taken place throughout the whole of the district.

He did not pretend, that there was any great novelty in the works, but they had been very successful for the purposes for which they had been designed.

Mr. Bidder,—President,—said, the Paper had excited hopes, which had not been allayed by the remarks addressed to the Meeting by the Author. He could not believe, that all the facts connected with the works of the Severn had been detailed, because, so far as he understood the results, they had been produced without adequate causes. It, certainly, was difficult to perceive how the placing of a weir in a river, could have the effect, without other auxiliary works, of relieving the adjoining lands from the flood water. The reasoning by which that view was attempted to be supported was, he thought, not quite correct. It had been said, that by introducing a weir, the water above it was deepened, and that when the floods came down, they met with deep, instead of shallow water, and were carried off, consequently, with greater velocity. But if the floods came down a river denuded of water, they would first have to raise the water to the height which the weir had created, before it could discharge itself down the river. Neither could he understand, that the erection of a weir should increase the scouring power of a river, nor that a particular parabolic curve at the back should augment the flow over it, 9 inches to 12 inches, which was equal to 50, or 60 per cent. The River Severn was one with which he was not intimately acquainted, having only once passed up it in a row-boat; but

it was a river which, undoubtedly, presented natural phenomena of an interesting character, which deserved to be carefully recorded. He regretted, therefore, that a Paper of so much interest, did not convey sufficient information to be able to fully appreciate the value of the works which had been so ably carried out. He hoped the Author would, on some future occasion, present that information to the Institution, in a more ample and detailed form.

May 1, 1860.
GEORGE PARKER BIDDER, President,
in the Chair.

The following Candidates were balloted for and duly elected:—WILLIAM CUDWORTH, FRANCIS FOX, and LEWIS WAINWRIGHT SAMUEL, as Members; HENRY RUSSELL SHAW and GEORGE BARNARD TOWNSEND, as Associates.

No. 1,024.—"On Coal-Burning and Feedwater Heating in Locomotive Engines.[1] By DANIEL KINNEAR CLARK, Assoc. Inst. C.E.

THE general abandonment of coke as fuel in railway engines, and the use of the combustible in its normal condition as coal, will, probably, in the course of a few years, become an accomplished fact, as the change is now rapidly taking place. The immediate motive for it, is the necessity for reducing the expenditure on railways, in order to increase the dividends. As the cost of coke is, necessarily, greater than that of coal, and inasmuch as, with proper management, a pound of coal does as much duty as a pound of of coke,—occasionally, rather more,—the whole difference in cost of the two descriptions of fuel is economised. But there is the nuisance of smoke to contend with, on the railways using coal, when the coal is not completely burned and the smoke is not prevented, particularly in running without using the blast, and in waiting at stations. The term 'smoke nuisance' has only a relative signification dependent on the views and tastes of railway travellers, and of the public generally; but the term 'smoke prevention' has an absolute meaning, and those systems by which smoke is entirely prevented, must be considered the best.

The chemistry of the combustion of coal is now so generally understood, that it will be unnecessary to repeat it in this Paper, of which the chief object is to discuss the existing practice of coal-burning on railways; the Author, therefore, will proceed to a consideration of the physical conditions of the complete combustion of coal. These are; first, that the introduction of air should be in sufficient quantity, and suitably distributed amongst the solid and gaseous portions of the fuel in the furnace, altogether, or partially through the grate, and partially above the fuel directly to the

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[1] The discussion upon this Paper extended over portions of two evenings, but an abstract of the whole is given consecutively.

gases; secondly, that the temperature should be maintained sufficiently high within the furnace, so that it should not be lowered by external causes, during the combustion of the hydro-carbon gases, in order to effect the union of the element of carbon with its full proportion of oxygen; and thirdly, that the combustible gases should be thoroughly mixed with their supply of air.

QUALIFICATIONS OF THE ORDINARY LOCOMOTIVE BOILER FOR COMBUSTION OF COAL.—The thorough mixture of the gaseous elements with air, within the fire box, is the condition, the fulfilment of which constitutes the main difficulty in dealing with the locomotive boiler, because in burning coal, the space, or capacity must be open, in order that the gases in progress of combustion may freely intermingle; whereas, the necessary extension of surface for the absorption of heat, by means of the ordinary flue tubes, cuts up a large portion of the flue capacity of the boiler, divides the burning gases into isolated streamlets, and thus effectually suspends the continuous intermixture, instrumental towards the completion of combustion. The gases in front of the tube plate enter the tubes, just as they are located; where the mixture is rightly adjusted, combustion may proceed within the tubes, and be there completed; where there is too much, or too little air, combustion does not proceed. In practice, the latter is usually found to be the case; and, accordingly, when the columns of gas and air, released from confinement within the tubes, pass into the smoke box, and again commingle, combustion is frequently resumed there, and it may continue till the gases are disposed of at the top of the chimney. This is the cause of the blistering of smoke boxes and chimneys of ordinary engines, when coal is exclusively burnt; and they become, occasionally, red hot. Such results are not now, however, so common as they have been; for whilst the earlier engines passed off the gases at a high spontaneously-igniting temperature, through their short boilers, the more recently-built engines abstract a greater quantity of heat from the gases, on their passage through the boiler, and the gases are, of course, discharged at lower temperatures.

The unfavourable action of the flue tubes in suspending combustion, is commonly ascribed to their cooling the gases below the minimum temperature requisite for the maintenance of combustion, and thereby, cutting short the process altogether. It is not so; because either the rate of conduction of heat through the substance of the tube, or the rate of absorption of the heat by the water, would be totally insufficient to account for the presumed fall of temperature. Carburetted hydrogen, the combustion of which is the desideratum, burns at 800° Fahrenheit; and it is known, that in engines doing heavy duty, the temperature of the gases, after

having traversed the entire length of the tubes, is frequently above 800° in the smoke box. It is, in short, an ascertained fact, that the gases spontaneously re-ignite in the smoke box, where they are free to continue mixing with the air drawn either into that compartment with them, or through leaking joints. The cooling within the tubes is far from being so rapid as has been assumed. The extended length of flue, or 'run' available for the mixing and combustion of gases, pertaining to ordinary stationary boilers, contrasts forcibly with the limited fire box of the ordinary locomotive boiler.

The utility of the long run in stationary boilers is clearly established, by the observation of the lengthened flame, indicating lengthened, or deferred combustion in the flues. Mr. C. W. Williams, (Assoc. Inst. C.E.,) found, in one instance, that the flame extended to a length of nearly 30 feet in the flues, before complete combustion was effected. The locomotive boiler, then, as it stood, though excellently suited for the combustion of coke, was, according to ordinary practice, inferiorly constituted for effectually consuming coal, having neither time, space, nor run to facilitate the process. The defects of the multitubular-flue system had, in this respect, been experienced in the practice of marine boilers, in which the prevention of smoke appears to have been as nearly impracticable, as it has been in locomotives. There is, however, one condition favourable for smoke prevention in the locomotive; the peculiar intenseness of the combustion. Cornish stationary boilers, with flues indefinitely drawn out, burn coal at the low rate of 4 lbs. per square foot of grate per hour; common stationary boilers burn from 12 lbs. to 20 lbs. per foot per hour; and locomotive boilers consume 50 lbs. to 100 lbs. per hour. The more intense the combustion, the less is the required run, notwithstanding the increased speed of the draught, as the process of combustion is accelerated in a still greater ratio.

The comparatively superior strength of the draught in locomotive boilers is, however, directly beneficial in its power of drawing more, or less air through the grate, available for the combustion of the gases. A large quantity of free air is thus drawn in, mixed with the gases, and is quickly united with them; and there is no doubt, that in this way, by the introduction of air entirely through the grate, the combustion of coal is sometimes effected in the locomotive boiler, with very little smoke. But the result is variable, because the means are variable; and though an engine, whilst working with full steam, a powerful blast and a thin fire, may thus consummate the process of combustion, those conditions are wanting when the fire is thick, or the duty is light, as the draught is powerless to draw through the mass of the fuel, a sufficient quantity of free air. Still less favourable are the conditions, when

the steam is shut off after heavy duty, the natural draught of the boiler being totally insufficient for the purpose. Thus it is, that the discharge of smoke is greatest, when the engine is doing the least duty, and when the blast is off; and that, whereas in other classes of boilers, there may be a long run for the gases undergoing combustion, with a comparatively uniform duty and a uniform draught, in the locomotive boiler, the run is reduced to a minimum, and the duty and the draught are extremely variable, being both greater and less than those of any other class of boiler. It has been found, accordingly, that an extension of the grate surface is attended with a diminution of smoke in the combustion of coal, as the same mass of fuel spread over a larger area, is less in depth, and a larger quantity of free air may be drawn through it. The most efficient coal-burning locomotives, under circumstances otherwise the same, are those which have the largest grates; and these are found, practically, to require a very small proportion of air to be introduced above the fuel, whilst working with the blast.

Still further to assist in the prevention of smoke, in common locomotive boilers, an auxiliary jet of steam has been thrown into the chimney, in order to maintain the draught through the fire, when the steam is shut off from the engine. The steam jet is a very serviceable adjunct; and no doubt, it materially aids in the prevention of smoke. It is, indeed, an indispensable element in all existing plans for effectually burning coal in locomotives; and much of their superiority in smoke prevention, though it may be ascribed to other and more apparent characteristics, is based upon the action of the auxiliary jet.

With the limited fire box of a common locomotive boiler to deal with, enginemen have had recourse to various ways of treating the fire, in order to diminish the nuisance of smoke. They have relied, chiefly, on the instrumentality of the ash pan, the dampers, and the fire door, for carrying out a system of careful firing. They have endeavoured to prevent the formation of smoke, by controlling the admission of air through the grate, and adjusting it precisely to the requirements of the fuel; by similarly manœuvring the fire door, for the admission of air above the fuel; by stoking with large pieces of coal and deep fires, for heavy duty, and smaller coal with shallow fires, for lighter duty; by firing more frequently to lighten the duty and at all times, by keeping the bars covered with fuel, to prevent excessive local draughts through the grate. That much may be effected by these means, there is no doubt. It is well understood, that the nuisance of smoke on entering, or waiting at stations, may be very much, or in some cases, even altogether, subdued, by thoroughly closing the ash pan, and by opening wide the fire door.

Low-pitched doorways at the level of the fuel, introduce fresh

air to greater advantage than those which are set high, as the air through the low door mixes more quickly and more freely with the gases, as they rise. It was, accordingly, found advantageous to adopt the practice of charging the fresh coal, chiefly under the fire door upon the hind part of the grate, and subsequently, when relieved of its gaseous element, pushing it forward towards the tubes, thus making way for a succeeding charge behind. Such have been the usual modes of treating coal, as fuel, in locomotive boilers of the normal type, in their normal condition. But the elaborations of practice in ordinary boilers have been to a considerable extent, superseded, within the last year, or two years, by the methods recently introduced of admitting air above the fuel, near its surface and amongst the combustible gases. These methods may be classed as acting; first, by currents of air introduced through tubular, or other openings in the sides of the fire box, uniformly distributed over the surface of the fuel; and secondly, by the deflection of a body of air introduced through the doorway, upon and over the surface of the fuel. A different principle of operation has also been introduced, by constructing large and spacious fire boxes, with large grates and long runs.

The three leading classes of coal-burning boilers, thus indicated, are variously represented, in chronological order, by the diagrams; (Plate 6). First, the adaptation of large extended fire boxes and combustion chambers, by Mr. M'Connell, (M. Inst. C.E.,) in 1853; (Fig. 1); by Mr. Beattie, in 1855; (Fig. 2); and by Mr. Cudworth, in 1857; (Fig. 3).

In Mr. M'Connell's plan, (Fig. 1,) there is a large grate, a long run, and air tubes through the front and sides; and the system, though heavy on fuel, provides the greatest practicable area of fire grate, in order that the coal may burn with moderate intensity and free from clinker, and that plenty of air may pass into the fire box, through the grate, to consume the gases. The combustion is assisted by the introduction of air through the front and sides of the fire box; and a large capacity and length of run is provided, by adding a combustion chamber, which is, simply, an extension of the fire box into the barrel of the boiler. To provide for alternate firing, the fire box is divided longitudinally into two compartments. This plan is, with good management, tolerably effective in preventing smoke.

In Mr. Beattie's boiler, (Fig. 2,) as in Mr. M'Connell's, the grate is large, and the run is divided and extended, by the addition of a combustion chamber projected into the barrel, with brick arches and tiles. The fire box is divided transversely into two compartments, by an inclined water-space diaphragm. Both compartments are arched over with fire tiles, at narrow intervals; the combustion chamber also is stocked with perforated bricks,

or curved tiles, placed at some distance clear of the tubes. The fire tiles receive and retain a portion of the heat from the passing gases, when the fuel is incandescent and smokeless, and restore it to the smoke passing from fresh coal; thus acting as equalisers of temperature. The tiles, also, break up and mix the gases and air; and partly by mixing, and, it is supposed, partly by heating, they promote combustion. The first furnace is the most actively worked; the second is chiefly designed to carry incandescent fuel; and by means of independent ash pans and dampers, the admission of air through the grate may be adjusted for each furnace. Air is also admitted through the doors by small apertures, and similarly, through the back of the fire box, by slides. The gases from the first and principal furnace, pass through the tile bridge, are deflected by the hanging transverse diaphragm towards the hot fire in the second furnace, and then pass through the second tile bridge and the mass of tiles in the combustion chambers, before they enter the tubes. The object of this invention, which has already been submitted to the Institution,[1] is to equalise the temperature of the gases, to prepare the colder gases for ignition, under all fluctuations of temperature, and also to perfect the mixture of the gases and air, in order to effect their entire combustion. An auxiliary steam jet is opened into the chimney, when the blast is off, to stimulate the draught, and to prevent smoke. This plan works very well.

Mr. Cudworth's plan, (Fig. 3,) combines an inclined grate with a long run. The incandescent fuel slides forward, and the fresh coal is charged near the doorway. The fire box is divided, by a longitudinal diaphragm, into two compartments, making two furnaces, which unite in front of the tube plate. With the aid of an auxiliary jet in the chimney, Mr. Cudworth's plan may be made tolerably effectual in preventing smoke.

But it was necessary to adapt the existing engines, as they were, for burning coal without smoke, by simple means, and independently of extensive structural alterations. This had been attempted by Messrs. Gray and Chanter, in 1837, and again in 1839. They divided the fire box into two compartments, one for coal, and the other for coke; they also admitted air in streams, through tubes in the walls of the fire box, and they were the first who applied a steam jet in the chimney, when the blast was off, to maintain a draught. Mr. Dewrance, in 1845, divided the fire box into two parts, the furnace and combustion chamber. Messrs. Dubs and Douglas, in 1856, constructed a deflecting mid-feather, proceeding from the back of the fire box, towards the tube plate, to throw down the smoke over the incan-

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xvi., p. 41.

descent fuel; and Messrs. Evans and Dubs, in 1857, added to this, a moveable inclined grate, capable of being raised, or lowered, for the management of the fire. After various attempts, Mr. Yarrow, in 1857, projected an arch of brick from the tube plate towards the fire door, and admitted air through tubes in the tube plate under the arch, and through the fire door, to mix with the smoke. He has, subsequently, superseded the air tubes, by upright air bars near the tube plate; (Fig. 4.) In the same year Mr. Jenkins, admitting air through numerous air tubes in the tube plate, applied a curved partition across the fire box, to throw forward the air, distributing it through numerous small holes at the upper part; (Fig. 5.) He regulates the supply of air by a damper, and he has, more recently, added a row of air tubes under the fire door.

Towards the end of 1857, the Author, believing that a simple means of increasing the supply of air, and forcibly distributing and mixing it with the smoke, in a common open fire box, independently of internal appliances, was a desideratum, devised his system of steam-inducted air currents, in which, in its simplest form, air currents are admitted just above the fuel, by tubes, or otherwise, through the sides of the fire box, and are forcibly accelerated, by means of jets of steam, directed from the outside, through the openings, into and across the fire box; the steam nozzles operating through the air tubes, as the blast does in the chimney. In December, 1857, the Author applied his system to one side of a small stationary locomotive boiler, at the railway foundry, New Cross. There were two air tubes, and a jet of steam to each tube, from small nozzles on the outside, $\frac{1}{16}$th of an inch in diameter, to increase the quantity and velocity of the air introduced. This simple apparatus was for several months in operation, and the dark smoke which was discharged when it was not in action, was entirely prevented by its use. In January, 1858, tank engine No. 12, on the North London Railway was fitted with four air tubes, $1\frac{1}{2}$ inch in diameter, through one side only, the other side being inaccessible. With the assistance of jets of steam, of $\frac{1}{16}$th of an inch, smoke was completely prevented, when the surface of the fuel was below the level of the air tubes. In April, 1858, passenger engine No. 64, on the Eastern Counties Railway, was fitted with a row of air tubes on each side, four on one side, and three on the other, with steam nozzles, one to each air tube. With this application, the engine worked the main line trains for eight, or nine months, and the smoke was, in general, effectually prevented. In January, 1859, passenger-engine No. 9, on the South Eastern Railway, was fitted and put to work, with two rows of air tubes through the front and back walls of the fire box, seven in each row, or fourteen in all, with induction nozzles to every tube; (Fig. 6.) The per-

formance of this engine has been quite satisfactory, and it has continued at work, thus fitted, up to the present time. On the Great North of Scotland Railway, engine No. 5, was fitted on the Author's system, with front and back air tubes, under the direction of Mr. Cowan, the locomotive superintendent, and was started in March, 1859. The results have been, in all respects, satisfactory, and the same system has been applied, by the superintendent, to the entire locomotive stock of that railway. Fig. 7 shows its application to the goods engines, now in course of construction by Messrs. Robert Stephenson and Co., for the same line. The Author's system has also been adopted on the Londonderry and Enniskillen Railway. In 1859, it was applied to some of the tank engines on the North London Railway, the back air tubes being placed high, to clear the water tank, and the grate being inclined to correspond. It was, occasionally, found, that the back jets, placed so high above the front ones, drew the smoke into the flue tubes; and that the front ones, impinging directly upon the fuel, did not clear the smoke so effectually as when the back jets were afterwards removed, and the grate levelled, so that inducted currents passed above the fuel. In 1859, one of the old passenger engines, No. 89, of the London and Brighton Railway, was fitted with the Author's apparatus, with a row of air tubes, and induction jets in the front only. Accidental circumstances rendered impracticable, the insertion of air tubes in the back. Smoke was effectually prevented, except when heavy charges of coal were delivered at once.

On the Great Western Railway air is admitted into the fire box, over the fuel, by numerous air tubes, regulated by slides, through the front, sides, and back. On the Oxford, Worcester, and Wolverhampton Railway, a system was introduced, by Mr. Edward Wilson, in 1858, in which air is conducted from the front of the smoke box, through several of the lower flue tubes, into the fire box; (Fig. 8). On the northern division of the London and North Western Railway, Mr. Ramsbottom introduced air under a brick arch, by two openings 7 inches square, through the front of the fire box; (Fig. 9).

With respect to the class of contrivances, acting by deflection, the initiative appears to have been taken, on the Birkenhead Railway, by Mr. Douglas, who, in January, 1858, applied a deflecting plate, fixed to the inner side of the door, through openings in which air was admitted, whence the air passed, and was deflected towards the fuel. In June, 1858, on the same line, a moveable deflecting plate, and an under-hung door, with a sector and notches to regulate the opening for air, was applied, and, more recently, a plain inverted scoop, or shovel; (Fig. 10). In July, 1858, on the East Lancashire Railway, Messrs. Lees and Jacques fixed the de-

flector to the door which was under-hung, and was provided with a valve, the opening of which was regulated by a sector. They built, in addition, a narrow brick arch against the tube plate, so that the smoke and air might, by their combined action, be better intermixed; (Fig. 11). In December, 1858, Mr. Sinclair, (M. Inst. C.E.,) on the Eastern Counties Railway, applied a baffle plate inside the fire box, hung over the doorway, and an under-hung door regulated by notches, with two steam roses, one on each side of the fire box, to project steam downwards upon the fuel, when the blast was off; (Fig. 12). This system was introduced by Mr. Frodsham. In 1858-9, an inverted shovel, or scoop, similar to Mr. Douglas's, but longer, was rather extensively introduced, being placed in the doorway, and inclined towards the centre of the fire, in order to deliver the air directly on the top of the fuel.

It has not been attempted, in the foregoing notices, to describe all the plans that have been designed for the purpose of consuming coal without smoke in locomotives; the intention has been to show generally, the directions in which Engineers have looked for the means of insuring complete combustion. There is one feature, of considerable importance, which is common to all; the steam blow-pipe, or auxiliary jet, in the chimney. This is made use of, for the purpose of continuing the draught of the furnace, when the powerful artificial stimulus of the blast is, at intervals, suspended. The action of this smoke annihilator is well worthy of study; and it is a question of direct practical interest, to ascertain the reason of the blow pipe operating thus serviceably. Looking into an ordinary fire box, at rest, under the action of the blow pipe, smoke may be perceived in the fire box, wending its way into the tubes, which becomes totally invisible at the top of the chimney. This visible smoke is rendered invisible, either by absorption, or precipitation, or a little of each, and by the steam from the blow pipe; the jet of steam 'paints the smoke.' Imperfect though such a mode of banishing smoke may appear, it is, nevertheless, true, that every one of the coal-burning contrivances falls back to a greater, or less extent, upon the blower, for the means of consummating the extinction of smoke. The action of the steam blast in destroying visible smoke, while the engine is at work, is apparent to the most ordinary observer, inasmuch as the discharge from the chimney, which may be clear and colourless when the blast is on, may become densely brown, or black when the blast is off, and may only be mitigated by a discharge of steam from the blow pipe. That steam possesses a considerable power of precipitating the particles of smoke, may readily enough be observed over an ordinary domestic fire, by directing into the ascending smoke, the steam spouting from a kettle; it is found to banish the smoke in a greater,

or less degree, certainly not by any act of combustion, or other chemical process, but by simple physical action. And, it is in virtue of the same faculty of absorbing, or precipitating the particles of smoke, that certain processes for preventing it operate, by passing the smoke into intimate contact with water. It is found, similarly, that smoke from stationary chimneys is subdued, or mitigated by discharging the exhaust steam into the chimney. Of course, the action of exhaust steam, so directed, in accelerating the draught, and thus in another way diminishing smoke, is distinguishable from its action as a precipitant, or absorbent; but, in many cases, doubtless, the prevention, or reduction of smoke by the agency of steam in the chimney, is mainly due to its operation in the latter capacity.

It cannot properly, therefore, be assumed, that combustion is, in every case, complete, when smoke is prevented by the agency of steam in the chimney: whether the engine is running under the blast, or standing under the blow pipe. This is a fair subject for practical investigation: in the meantime, one conclusion of practical value may be drawn from the general experience of the smoke-preventing agency of steam, that observers should be on their guard not to be misled by appearances, and should not be diverted from the accomplishment of the main object, the thorough combustion of coal by the ample admission and the intimate mixture of air above the fuel, and amongst the smoke. It may be added, that where pure steam is discharged upon, or over the surface of the fuel, whilst it operates favourably in preventing, or reducing smoke, it also damps the fire, and retards combustion; such at least, is the tendency of this mode of using steam, so far as it has come within the Author's experience, in whatever way it is introduced. Consequently, modes of smoke prevention by the sole agency of pure steam, over, or upon the fuel, are usually attended by a difficulty in making steam, and a great expenditure of fuel.

The necessity for admitting a supply of air above the fuel, is understood and acknowledged by all, whether it is introduced through the grate, or otherwise. When the grate is very large, and a thin fire is maintained, the supply of air may be taken almost entirely through the grate. It is, however, indispensable to this mode of managing the fire, that the fuel should be carefully supplied, at short intervals, and in small quantities, uniformly distributed; in recognition of the principle, that the more nearly uniform the supply of fuel, the more so is the generation of combustible gases, and the more probable, accordingly, is the combustion of these gases, and the prevention of smoke. With inclined grates, of course, the fuel is only deposited near the entrance, and it finds its way down, by gravitation; and their greater ease of management, in this respect, notwithstanding the frequent stoking they require,

compared with ordinary level grates, mainly constitutes their superiority. With small, or moderate-sized level grates, a coal fire demands still greater care than with larger grates, where smoke is to be prevented by air from the grate. The firing must be still more frequent; and as the door, of course, is more frequently opened, another evil is incurred, the admission of a large proportion of cold air into the fire box, most of which passes off unburnt through the tubes, chilling the boiler, and checking the production of steam. Such evils are much reduced in magnitude, by the simple process of admitting fresh air for the combustion of the gases, otherwise than through the fuel, in greater, or less proportions, according as it may be utilised; and as this independent admission of air is a very simple process, there can be no reason for endeavouring to dispense with it.

It may be adopted as an axiom in locomotive practice, that an independent supply of air should be admitted above the fuel, for the purpose of burning the combustible gases; and that the air so admitted, must be thoroughly mixed with the gases. Length of run promotes the mixture, and in Mr. Beattie's boiler, the mixture is further advanced by the interposition of fire tiles. The brick arch in the common fire box operates beneficially in the same way, doubling the run, and promoting the mixture. The baffle plate, the hood, and the scoop operate reversely, and with considerable success, by inverting the draught of the air admitted through the doorway, and directing it over the surface of the fuel. The baffle plate is objectionable in inducing by its action, the suction of particles of coal through the flue tubes, and the burning of the smoke box, unless counteracted by an internal brick arch; and the system requires powerful blow pipes in the chimney. To insure the prompt and effective mixture of the air and gases, the air should be admitted and distributed at the surface of the fuel. But the ample admission and intimate intermixture of air with the gases above the fuel, must be effected in conjunction with a sufficiently high temperature; and this condition has led to the adoption of various modes of heating the air, or the gases, or both, prior to, or at the time of mixture. Mr. M'Connell suggested the use of an air chamber within the smoke box, in which air was designed to be heated, and led into the fire box through tubes. Mr. Wilson conducts air from the front, through the smoke box and the boiler, by a number of the flue tubes, and these also partially heat the air on its way to the fire box, letting down the steam in a proportionate degree. Mr. John Gray established a coke fire on a supplementary grate, as a reservoir of heat within the fire chambers; and Mr. Beattie embeds his reservoir in masses of firebrick. Others attempt to heat the air by conducting it partially over the surface of the fire-box shell. Expedients of this

class operate, in some degree, advantageously; but in the adoption of such supplementary contrivances, it appears to have been overlooked, that there is abundance of heat within the incandescent fuel itself, to supply the demand for temperature. Mr. C. W. Williams states, that the combustible gases themselves, taken at their origin, are, in general, sufficiently high in temperature to sustain combustion with cold air; and it is demonstrable in practice, that this may be simply and naturally effected, by the preliminary process of heating the air at, or near the surface of the fuel, whence the gases emerge at their highest temperature, and where the radiant heat from the fuel is at its maximum intensity. In boilers with internal furnaces, more than in others which have their furnaces surrounded with brick, this immediate process of mixture and combustion is needful, inasmuch as the absorption of heat by the surrounding surfaces, and the decrease of temperature in the atmosphere of the furnace, take place more promptly in the former, than in the latter.

The problem of the direct and efficient combustion of coal, in the ordinary locomotive boiler, appears to resolve itself into the immediate and thorough intermixture of a plentiful but regulated supply of air, with the ascending smoke, or combustible gases at, or near to the surface of the fuel. Practically, it is found necessary, for this object, to operate from both the front and the back of the fire box; admitting air, or using arches, deflectors, or bafflers, or doing both, as has already been described. But these contrivances, which deal with air in bulk, though generally effective in preventing smoke, are usually attended by the escape of a considerable quantity of unconsumed air through the flue tubes, and a difficulty, in many cases, in keeping up the steam at high speeds. The various forms of door-way deflectors are also objectionable, as previously stated, in facilitating, by their mode of action, the suction of particles of coal through the tubes, and the burning of the smoke box, unless counteracted by an internal arch. The Author has found, by experience, that to burn smoke when the engine is running, it is sufficient, that the air should be admitted at, or near the surface of the fuel, by air tubes distributed over the width of the fire box in the front and the back, without the aid of internal arches, or deflectors. The draughts of air, through the front tubes particularly, are very strong when the engine runs ahead, and they carry the currents into the middle of the fire box, where they meet the counter-currents from the back, effect the mixture of the air and smoke, and prevent the suction of small coal through the tubes. But in all systems applied to ordinary fire boxes, operating by means of the draught available in a locomotive engine, aided, when the blast is off, by the steam jet in the chimney, range of power is wanting to overtake the extremes

of intense ignition and rapid generation of smoke-making gases, immediately after the steam is shut off, or when fresh fuel is added; and also to suit itself to the quiet state of the fire when the glow and excitement subside, as well as to all the varying conditions of a locomotive furnace. The means of extending the range, volume, and power of the air currents, and of adjusting them to the wants of the furnace, are supplied by the instrumentality of the jets of steam employed by the Author, as means of inducting and accelerating currents of air. The steam nozzles, with the air tubes towards which they are pointed, are like so many miniature blast pipes and chimneys, turned into the fire box; and they possess, relatively, the same power of urging and creating draught. By this method of steam induction, the air currents are delivered with such precision and velocity, as to sweep the whole surface of the fuel, and forcibly, to distribute the air amongst the gases. Of the virtue of forcible impingement in promoting and accelerating combustion, numerous examples occur in ordinary practice. It is in virtue of this principle, that the ordinary bellows accelerate ignition; and if the upper front of a fire place is closed with a sheet of paper, to direct the draught through the bars, upon the fuel and combustible gases, the air currents so deflected and forcibly directed upon them, consume the gases and prevent smoke. The contracted neck of the glass tube of a moderator lamp, adjusted so as to direct the ascending air within the tube, upon the upper part of the flame, increases its volume and brightness. In Mr. Beattie's boiler, the smoke-consuming process is, to a great extent, based on the same principle of forcible mingling of the air and gases amongst each other, as they roll against the fire tiles and diaphragms. By the Author's process, the entire operation is consummated within the four walls of an ordinary fire box, the inducted currents sweeping up the gases and forcibly intermixing with them.

In practice, it is only, occasionally, necessary to put the steam jets in action when the engine is at work, if the air openings are sufficiently numerous, as the action of the blast alone draws a large supply of air through them into the fire box. The time at which the full inducting power of the jets of steam is in demand, is immediately on the steam being shut off, when the engine is drawing up to a station. Then the heat in the fire box is fierce, and there is an extensive distillation of combustible gases, which are discharged as smoke from the chimney, unless met and consumed by the inducted currents above the fuel. The intenseness of the heat, of course, subsides rapidly, and the jets may be moderated as desired, and be continued in action till the engine is again in motion.

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would be greater than that of coke.

again in motion.

The in-draught of air into the fire box may be regulated by the use of slides, or dampers over the air openings. But, by so limiting the number of air openings, and consequently, the supply of air, as to prevent any material excess of supply when the fire is in its ordinary condition, the dampers may, in practice, be dispensed with, without prejudice to the economy of fuel. And, inasmuch as, in ordinary locomotive working, the fire is unavoidably subject to extreme changes,—dull, for example, and evolving gas when the blast is on, or bright and intense, and profusely distilling combustible gases when the blast is off,—it is evident, that the air channels do not, and cannot, at all times, supply the requisite quantity of air for perfecting the combustion, with the requisite velocity of impinging action for accelerating it. The desideratum suggested by this deficiency is supplied, in a direct and effective manner, by the method of steam-inducted air currents.

In comparing the merits and performances of various methods of coal-burning without smoke, there is the difficulty of diversity of circumstances to contend with, as to weather, fuel, engine, and duty. The data contained in Table I. of performances, (facing page 558,) will, nevertheless, be useful for general comparison. The Table comprises the principal results obtained by the Author, of the performances under different systems of coal-burning, with comparative statements of the performances of the same, or similar engines burning coke. Of the three systems of extended fire boxes, by Mr. M'Connell, Mr. Beattie, and Mr. Cudworth, it appears, that with nearly equal gross weights, 102 tons to 116 tons of engine, tender, and train, and at nearly equal speeds, Mr. M'Connell's system consumes 35½ lbs. of coal per mile, Mr. Beattie's 24 lbs., (the feedwater heater being shut off,) and Mr. Cudworth's 26 lbs.; or, per ton gross,—Mr. M'Connell's system consumes 0·31 lb., Mr. Beattie's 0·235 lb., and Mr. Cudworth's 0·225 lb. The evaporative powers rank in the same order; i. e., Mr. M'Connell's evaporates 5·9 lbs. of water per lb. of coal, Mr. Beattie's 8·31 lbs., and Mr. Cudworth's 8·6 lbs. The excellence of Mr. Beattie's and Mr. Cudworth's systems is to be ascribed, to the proximity of the radiant heating surface to the fuel and the flame, and in both systems, the steam is well kept up.

Comparing coke with coal on similar duty, whilst Mr. M'Connell uses one-half more coal than coke, Mr. Cudworth employs, upon the whole, rather less coal than coke, the general average being 27·3 lbs. of coke, against 25·8 lbs. of coking coal per mile, or 5½ per cent. less coal than coke. But he has found, that coking coal ranks higher in evaporating power than other coals he has tried,—Lord Ward's coal and Ruabon coal,—of which the consumption would be greater than that of coke.

Of the systems of coal-burning engrafted on the common fire box, Mr. Yarrow's consumes 26·8 lbs. of Scotch coal against 22·1 lbs. of coke per mile, on the same duty, showing an excess of 4·7 lbs., or 21 per cent. more coal than coke. Mr. Jenkins uses 30·35 lbs. of coal against 32·43 lbs. of coke, or 6 per cent. less coal, on the Lancashire and Yorkshire Railway, under his own direction. When tried on the Brighton Railway, his system used 6·4 lbs., or about 23 per cent. more coal than coke. Mr. Lees's system, on the same line, used 5 lbs., or about 20 per cent. more coal; and the Author's system, on the same line, and on the same engine as that upon which Mr. Jenkins's plan was tried, used only 2·1 lbs., or about 7½ per cent. more coal than coke.

On the Eastern Counties Line, the Author's system, working against a strong wind, used 11 per cent. more coal than coke, working in a calm; and on the North London Railway, the same weight of coal as of coke, was used, viz., 26 lbs. per mile.

The Author's system has been best applied on the South Eastern, the Great North of Scotland, and the Londonderry and Enniskillen Railways, for elsewhere, the air admitted was deficient in quantity; and it is to its performance on these lines, that he wishes to direct the attention of the Members. On the former line, 14·4 lbs. of coking coal was used against 16·28 lbs. of coke per mile in a similar engine, on the same duty, for twelve months, showing a consumption of 11½ per cent. less coal than coke. On the Great North of Scotland Line, there has not been an opportunity of trying coke against coal for long periods, as coal has for several years been largely consumed, along with coke, on that line. But engine No. 5 was put upon trial for several weeks, burning English coke alone, against different kinds of Scotch coal. The trains, as well as the weather, were variable; but under similar circumstances, 9 per cent. less coal than coke was consumed, per ton of the gross moved weight of the train. At the same time, whilst 8⅝ lbs. of water appeared to be evaporated per lb. of coke, the water raised per lb. of coal, averaged only 8 lbs. Thus with a lower evaporative duty, there was a higher working duty with coal than with coke. This may be ascribed, probably, to the great command of steam afforded by the use of coal, in these engines.

In comparing the coal-burning practice on different lines, the inferior strength of Scotch coal to that of English coke and coal is to be borne in mind. The frequency of the stoppages is another element, as every stoppage of a passenger train, under ordinary circumstances, occasions a delay of from three minutes to five minutes, as compared with a through-running train. Table II., (facing page 560,) contains a selection of cases for comparison from Table I., for passenger, and for goods traffic. It gives the average

TABLE II.—PER

esigners.	Railway.				Calculated Equivalent Speed, without stopping.
					Miles per Hour.
McConnell	London and North W	..	..	..	42·
Beattie .	London and South W	..	..	..	34·
Cudworth	South Eastern .	..	..	..	32·
Douglas.	Birkenhead . .	..	..	..	29·
Yarrow .	Scottish North Easte	..	..	..	36·2
Connor .	Caledonian . .	..	..	..	33·3
Frodsham	Eastern Counties.	..	..	..	29·
Clark .	Great North of Scotl	..	..	..	32·

Douglas.	Birkenhead . .	..	..	..	..
Connor .	Caledonian . .	..	..	..	..
Frodsham	Eastern Counties.	..	..	..	..
Clark .	Great North of Scotl	Passenger and Goods .			..
		Ditto ditto, six months, January, 1860.			..
		Goods only			..

AVERAGE

Douglas.	Birkenhead . . .	..	..	..	..
Connor .	Caledonian . . .	..	..	..	..
Frodsham	Eastern Counties. .	..	..	..	..
Clark .	Great North of Scotla	..	..	..	..

number of vehicles drawn, and the gross weight of the engine, tender, and train; the average distance run between the stopping stations; the average speed including stoppages; the gross consumption of coal per train mile, and per ton gross per mile; also, in the last column, the equivalent speeds without stoppages, or such as would have been averaged had there been no stoppages, estimated in terms of an allowance, or deduction in time, of four minutes for each stoppage actually made by the passenger trains, except for the Birkenhead trains, with which, owing to the frequency of the stoppages, the actual delay is only three minutes per stoppage.

Of the systems based upon the ordinary fire box, those of Mr. Yarrow and of Mr. Douglas show the greatest consumption of fuel, and the Author's the lowest. Thus, the former, with 86 tons and 90 tons gross weight of passenger train, consumes 27 lbs. to 28½ lbs. per mile; whilst the latter with about 110 tons gross weight, consumes only 21 lbs. of coal, or one-fourth less. The systems of Mr. Frodsham and Mr. Connor occupy intermediate positions in the scale of consumption, which are more exactly defined by the rates of consumption per ton gross, as follows:—

By Mr. Douglas's system.	0·32 lb.	of coal,	per ton	gross	per mile.
„ Yarrow's „ .	0·32 lb.	„	„		„
„ Connor's „ .	0·26 lb.	„	„		„
„ Frodsham s „ .	0·25 lb.	„	„		„
„ Clark's „ .	0·19 lb.	„	„		„

The calculated equivalent speeds, are, no doubt, various, but the differences will not account for the variety in the consumption. The Author's system is shown to consume but five-eighths of the fuel used by Mr. Douglas and Mr. Yarrow, and only three-fourths of that used by Mr. Connor and Mr. Frodsham. It is also shown to be more economical in fuel per ton gross, than either of the systems with elongated fire boxes and combustion chambers.

In comparing the Author's system with the others, in taking goods trains, it is also found to consume less fuel per ton gross, where the trains are of equal weight. As, on the Great North of Scotland Railway, the goods engines, until lately, worked both goods and passenger traffic daily, the passenger and goods trains are averaged in two entries for that line in the second part of Table II.; the third entry contains the working of goods traffic only, in February and March, 1860, in stormy weather. The Great North of Scotland Railway has long gradients, many of them 1 in 100 to 1 in 150, with quick curves, and the goods engines ascend these inclines, at the rate of ten miles per hour, with thirty-five fully-loaded waggons, each weighing 12½ tons to 14 tons gross, or a gross total train weight of 460 tons.

FEEDWATER HEATERS. — In their application to locomotive engines, Mr. Beattie has laboured with considerable success, at feedwater heaters, using the exhaust steam for the purpose. The results of the working of Mr. Beattie's heater in 1856, have already been communicated to the Institution,[1] when a saving was found of at least 15 per cent. of fuel by the use of the heater, as compared with cold water; a conclusion which has been confirmed by the experience of others, in locomotive practice. In Mr. Beattie's earlier form of heater, the feedwater was discharged through perforations in the end of a pipe, into a chamber, placed in front of the chimney, where the exhaust steam was freely admitted. By this plan, the water was raised to a temperature varying from 180° to 190° with an ordinary blast, or 212° with a heavy blast. Mr. Beattie has, more recently, employed a surface heater,—consisting of a steam pipe from the exhaust within a water chamber, the feedwater circulating in the annular space,—in combination with a cistern below the footplate, into which the feedwater is delivered from the tender, through a ball cock, to regulate the supply, and is dropped through a perforated plate. Into this chamber the exhaust steam also is discharged, after having passed through the annular heating chamber. In this apparatus, though it is complicated and expensive, the water is well heated, but occasionally, the influx of the water to the cistern is prevented, by the counter pressure of the exhaust steam. Mr. P. Stirling, of the Glasgow and South Western Railway, states, that a saving of $11\frac{1}{2}$ per cent. of fuel has resulted from the use of this apparatus;[2] but it has been since discontinued, as it was found difficult to be kept in order.

The Author has recently introduced a simple and compact feedwater heater, (Fig. 13,) in which the steam from the blast pipe is projected into a short tube, in conjunction with the feedwater, which is delivered in a thin annular sheet around the steam nozzle. The steam forcibly impinges upon and breaks up the water into spray, and is instantly absorbed by the water, which may be heated to any degree of temperature. The steam operates partly by suction, in inducing the influx of the water, and partly by driving it before it, and so aiding the hot water pump, by the acquired momentum of the water. This apparatus is in process of application to locomotives, and has been employed, for some mouths, on a non-condensing stationary engine, of 20 nominal H.P., working at a pressure of steam of 60 lbs. per square inch. In its first form, the temperature of the feedwater was raised 120°, and the

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xvi., p. 41.

[2] *Vide* "Transactions of the Institution of Engineers in Scotland." Vol. ii. "On Coal-burning Locomotive Engines."

saving of fuel by its use was 10 per cent. In the second form, the water was heated from 39° to upwards of 191°, the engine making forty revolutions per minute, when the saving was greater, though it was not measured. There is no doubt, that the heater may be made to heat the water to the boiling point, and it is well adapted for agricultural and other engines on wheels, where lightness and compactness are important considerations.

The Paper is illustrated by a series of diagrams, from which Plate 5, (Figs. 1 to 13,) has been compiled.

[Mr. D. K. Clark

Mr. D. K. Clark wished to direct special attention to certain important points in the working of coal-burning locomotives. In the first place, the steam should always be kept up, while the engine was running. In most of the systems in use, a considerable quantity of cold air was drawn through the flue tubes, the strength of the draught towards the flue tubes not allowing it to approach sufficiently near the surface of the fire, to mix with the smoke. In Mr. Connor's system, although the inclined plate, or deflector, at the doorway, gave the air a downward direction, yet, when it was under the action of a strong blast, the current undulated over the arch. In Mr. Douglas's and Mr. Frodsham's systems, the diverting action was still more injurious, because there was no assistance from a brick arch in bringing together the smoke and the air; the air did not strike upon the fire, but went at once towards the tubes. On that account, he thought the brick arch a very useful adjunct, in connection with the inclined entrance of the air into the box. In the plan of Mr. Ramsbottom, the air was introduced in too large a body, through only two places, and, therefore, a great quantity of it must pass through unmixed. He had come to the conclusion, that the air, where it entered the box, should be introduced at the proper level for immediate mixture with the smoke.

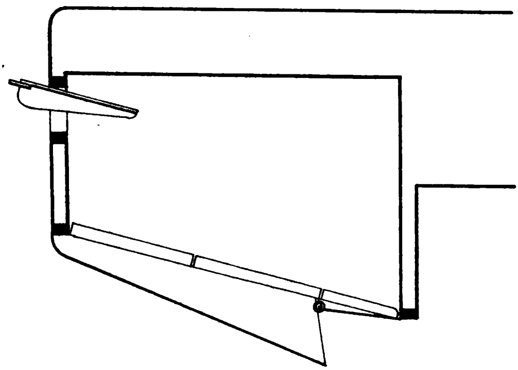
But if it was necessary to keep up the steam when the engine was working, it was also important to keep down the steam whilst the engine was standing at the stations, or running without steam on. The chimney blower was required, in order to create a sufficient current of air in the fire box to consume the smoke. Where tubes were placed in the front and back of the box, and induction jets were used, instead of a jet in the chimney, as the nozzles operated above the level of the fuel, the tendency was to prevent the draught through the grate, and thus to suspend the generation of smoke, as well as the consumption of fuel. This was the reason that the steam was not so liable, in this system, to rise to a dangerous pressure.

Another important point was the question of management. It was desirable, that any system employed should be capable of being easily managed; and as the difficulty principally occurred at high speeds with express trains, he considered that which required the least fuel, and the least labour from the stoker, was the best.

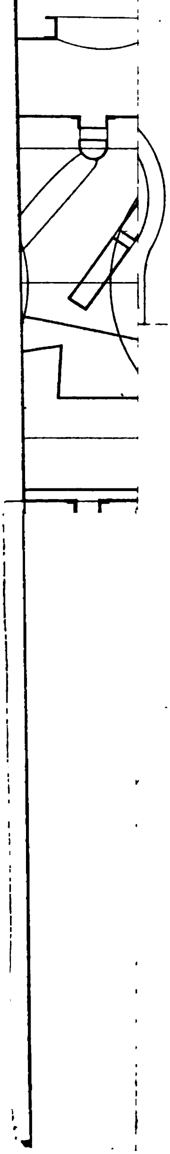
He thought, that with deflectors, there was a large quantity of cold air introduced into the fire box. He had taken the sectional areas of the air entrances in some of the systems he had alluded to. In Mr. Connor's plan, for example, the sectional area of the entrance was 67½ square inches, or 5 square inches per square foot of grate. In Mr. Ramsbottom's system, it was 7 square inches per square foot of grate. In Mr. Sinclair's arrangement of Mr. Frodsham's system, upon the Eastern Counties Railway, the area of entrance

IN LOC

Fig. 10.



DOUGLAS' SYSTEM, BIRKENHEAD RAILWAY.



was $5\frac{1}{2}$ inches per square foot of grate. In his own apparatus, the area had been as low as 3 inches; and the maximum allowed was 4 inches per square foot of grate. A plan had been applied to one, or two engines on the Caledonian Railway, for supplying the air direct upon the top of the fire, through a wide spout from the doorway; and that plan was more effective than any other upon the deflecting principle, and was worked with a small sectional area of air entrance. The exit of the air was about 3 inches above the usual level of the fuel, and the air was discharged upon the middle of the fire. A similar plan was employed upon the North London Railway, but it was even simpler; it consisted in using a long shovel instead of a short one, reaching to the middle of the fire box, with an arch. The brick arch appeared to be considered an essential adjunct, in the present practice of coal-burning on railways.

The feedwater-heating apparatus was simply applied to locomotive engines, in the form of a pipe on one side, and a return pipe to the other side. It did not alter the arrangements of any existing engines.

Mr. Hawkshaw, V.P., had noticed, that in the comparisons made by the Author between his own system and those of others, he had only alluded succinctly to that of Mr. Jenkins. Mr. Hawkshaw had long been acquainted with that system, and it was now extensively applied, at a very small cost, on the Lancashire and Yorkshire Railway. He thought it one of the best, because it was the simplest. One great advantage it possessed, was that it did not interfere with the future use of coke, in the locomotives to which it was applied. It was also free from most of the objections urged against many of the systems of smoke-burning. It mainly consisted in making a certain number of the stays hollow, instead of solid, with as many rows of apertures in the fire box as might be desired. Atmospheric air introduced in this manner, mixed with the products of combustion, and effectually destroyed the smoke. Moveable slides were fixed outside the fire box, by means of which the apertures could be opened and closed, at the pleasure of the engineman. When the apertures were closed, the locomotives were fitted for burning coke as before. He had sent to India, several engines fitted with this apparatus, on account of the equal facility which it afforded for burning either coke, or coal, as circumstances might render necessary. As far as he understood the Author's system, it seemed to be nearly the same as that of Mr. Jenkins, except that the former introduced jets of steam through the apertures. As the latter system had been some time in use upon the Lancashire and Yorkshire Railway, and had effected, as he believed, a large saving in

fuel, he thought it was entitled to more notice than had been bestowed upon it in the Paper. The Author had referred to the difference in the consumption of coal by Mr. Jenkins's system, when applied on the Lancashire and Yorkshire Railways and on the Brighton Railway; but was the same description of coal used in both cases?

Mr. WRIGHT observed, that the experiments on the railway were entirely conducted by his Brother, and he was not in a position to state the results. He only knew, generally, that a considerable saving was considered to have been effected, by the adoption of the system.

Mr. FLETCHER inquired, when the jets were most in use; whether with the engine running, or standing still.

Mr. D. K. CLARK replied, that the steam jet was used, occasionally, whilst running, but it was mostly used when the engine was standing still. Staveley coal was employed in the comparative trials on the Brighton Railway, but he took no part, personally, in the experiments.

Mr. G. BERKLEY remarked, that the plan with hollow stays, which had been described, was tried, about nineteen years ago, on the Midland Railway, and was the invention of Mr. Hall, (of Basford). He had also made experiments himself, and with results similar to those at present given. The evaporation of water was from 5 to 15 per cent. less per lb. of coal, than per lb. of coke. An objection was made at the time, that the tubes for the admission of air were liable to be burnt, and he had yet to learn, that such was not still the case. Economy, however, was the order of the day, and where coal could be obtained at much less cost than coke, a want of simplicity, or slight additional repairs would be overlooked. He found, generally speaking, that in the north, coal was not used for the engines; on the North Eastern Railway, it had not been introduced, or only to a slight extent. This was owing, probably, to coke being almost as cheap as coal, in the north of England; so also it was at Bombay. In coal districts, or where there was a large charge for freight to be added to the first cost of the fuel, there was little, or no advantage in using coal. Practically, there was only a saving where the price of coal was considerably lower than coke, but it was obtained at a sacrifice of cleanliness, and, to a certain extent, of simplicity. Mr. Hall's plan and that in use on the Great Western Railway, which was the same as Mr. Hall's, had not been mentioned in the Paper; this was a serious omission. If the complexity was not found objectionable, the introduction by the Author, of the nozzles for blowing steam through the hollow stays, to mix the air with the incandescent gases, commended itself to notice.

Mr. W. H. BARLOW remarked, that upon the Midland Railway there was in operation, a very simple, but efficacious, contrivance, which cost only a few shillings. It consisted of a broad, inclined shovel, placed on the top of the fire-box door; there were no hollow stays and no brick arches. It was assisted by a small jet of steam in the chimney, during the stoppages at the stations; but when the engine was running, the jet was not used. This simple and cheap arrangement was employed, with complete success, upon all classes of engines.

Mr. LONGRIDGE said, that the plan introduced upon the Midland Railway, had particularly come under his notice. He regarded the Author's plan as essentially the same as that introduced, many years ago, by Mr. Hall; a system of hollow stays, introduced into the fire box, by which the air was brought in, to mix with the hydro-carbons. The chief fault found with the system, at the time it was brought forward by Mr. Hall, was, that when an engine was standing at a station, it emitted black smoke. Mr. Hall remedied this, by a small steam jet in the chimney, to create a draught, whilst the engine was standing still, and thus the smoke was effectually prevented. Objections were then raised to the whistling sound of the steam jet, and eventually, the plan was abandoned. He thought, if more willingness had been exhibited by the officers of the company to assist in bringing the plan into working operation, Mr. Hall might have carried it out quite as well as others who had followed him.

Addressing himself to the general question, he said that, after a great many experiments upon the consumption of smoke, he had arrived at this conclusion, which he was satisfied was correct, that deflecting plates and brick arches were of little importance. All that was wanted, was sufficient air to mix with the hydro-carbons, and if it was moderately diffused over the surface of the fuel, there would be little, or no smoke. He had burnt at the rate of 66 lbs. per square foot of fire grate per hour, of bituminous coal, without emitting smoke from the chimney. With the apparatus proposed, many years ago, by Mr. Williams, he was able to introduce a sufficient amount of air, without deflecting plates, or brick arches. With respect to the jets of steam, it was curious, that in 1856, at the time he was much engaged upon this subject, among the plans which came under his notice, was one from Mr. Robert Longridge, of Manchester, who proposed to use hollow stays, with small jets of steam to promote the passage of a sufficient quantity of air. The reason of proposing jets of steam in that case, was, that in the boilers of marine engines, great difficulty was experienced in getting the requisite quantity of air, through the limited number of tubes which could be conveniently

used; but by employing jets of steam, the quantity of air passing through these hollow stays, might be greatly increased. With a jet of steam, as much air passed through a tube 2 inches in diameter, as through one 6 inches, or 8 inches in diameter, without the jet. In a locomotive engine with all the sides open, he did not see any difficulty in putting in a sufficient number of hollow stays, to admit the proper quantity of air for consuming the hydro-carbons. In the furnaces of marine engines for burning north country steam coal, there should be an air entrance of about 4 square inches per square foot of grate. With that amount of area, any gas coal could be burnt without smoke; with less, a sufficient quantity of air would not enter, unless aided by an artificial draught.

The only other point to which he would allude, was the comparative heating powers of coal and coke. This subject was discussed in a Paper, "On the Evaporation of Water from Steam Boilers," which was read at the Institution many years ago.[1] The theory then propounded was, that the same evaporative effect was obtained from coke, as from the quantity of coal from which it had been made. Having had considerable experience with coke ovens, he could not avoid the conclusion, that the flame which issued from them during the process of the manufacture, would boil water, and, therefore, he entirely dissented from that theory.

In a series of experiments with Garesfield coal and coke, which he made in conjunction with Sir William Armstrong and Dr. Richardson, at Elswick, in 1857-58, it was determined to settle this question. The best mode of treating coal, in order to produce the greatest amount of evaporative power, was first ascertained, and then the coke made from the same coal was similarly treated. The final result was, that the evaporative power of the coal comparatively to that of the coke was, weight for weight, as 100 to 89; the actual numerical quantities being:—

Water evaporated from 32° by 1 lb. of coal . .	lbs. 12·54
Do. by 1 lb. of coke made from the same coal . .	lbs. 11·16

But this was scarcely the correct way of stating the question. To produce that coke, the coal would be reduced at least one-third in amount, 100 tons of coals producing less than 66 tons of coke; consequently, taking the above figures, it would be found, that whilst 1 lb. of coal would evaporate 12·54 lbs. of water, the same coal converted into coke, would only evaporate $11{\cdot}16 \times 0{\cdot}66 = 7{\cdot}44$ lbs. of water; so that the true proportion was as 100 to 58. He

[1] *Vide* Transactions Inst. C.E., vol. ii., p. 16., *et seq.* and Minutes of Proceedings Inst. C.E., vol. i., (1838), p. 17, *et seq.*

could vouch for the accuracy of those results, and he thought they set at rest the theory to which he had alluded.

Mr. HAWKSLEY said, that having been engaged, incidentally, upon this subject, he was gratified at the account of the experiments made twenty years ago, upon the Midland Railway. Mr. Samuel Hall, (of Basford,) the pioneer of surface condensation, was also the originator, almost in its present form, of the system now in use for burning coal in locomotive engines. He was personally acquainted with Mr. Hall, and had taken some share in the experiments from which Mr. Hall obtained his economical results. The apparatus used was extremely simple, and it did not materially differ from some of the diagrams exhibited by the Author of the Paper. It consisted of small tubes, not originally intended for hollow stays, but afterwards frequently adopted for them, which were inserted in the sides, and sometimes, also in the front of the fire box of the engine. By this plan the smoke was almost, but not entirely consumed. The railway companies being then more particular with regard to the consumption of smoke, than they appeared to be at present, refused to adopt the plan which was, therefore, supposed to have failed; but so far as he knew, its success was fully equal to that now obtained with other apparatus. The smoke was not perfectly consumed under all circumstances, nor was it now, for the amount of dust and smoke, issuing from the coal-burning engines of the fast trains of the present day, was so considerable, that the windows of the carriages could not be opened, without covering the passengers, and filling their eyes with small particles of dirt and cinder.

Mr. Hawksley had also occasion, at that time, to make some elaborate experiments upon the relative values of coal and coke. As the Engineer of the Nottingham Gas Company, and of the Nottingham Waterworks Company, he had an opportunity of exactly determining the quantity of coke which could be manufactured, in closed vessels, from a given weight of coal. He had also the opportunity of trying the evaporative power of the coke, as contrasted with that of the coal from which it was made, under the furnace of a pumping engine, raising a known quantity of water to a known height. He found, upon the average of a year's working, that from 20 cwt. of coal of the midland counties, which was very different from the north country coal, 11½ cwt. of coke were obtained, besides other products. He then ascertained, that 6 cwt. of coke would evaporate exactly the same quantity of water as 7 cwt. of coal. It followed, therefore, that it required almost precisely 3 tons of coal reduced to coke, to produce the effect of 2 tons of the same coal, and consequently, there was a loss in converting the coal into coke for the purpose of producing steam; but considered only in reference to weight, coke had an advantage over

coal, in the proportion of 7 to 6. Such would be the result with most of the midland coals. The Derbyshire coal contained in every ton, no less than 300 lbs., or 350 lbs. of oxygen and hydrogen in such proportions as to combine, during distillation, and to form water: this quantity was, of course, entirely lost. Tar was another product of distillation, which was burnt in the ordinary process of forming coke, but which, in the process used for manufacturing gas, was caught in tanks; that amounted to another 100 lbs. per ton. So that, in every ton of this Derbyshire coal, there were from 400 lbs. to 450 lbs. of matter which could not be utilised in the shape of coke, in addition to more than 350 lbs. of inflammable gases which passed off in the conversion, besides carbonic acid and other non-inflammable gases, amounting altogether to more than 900 lbs. in every ton of coal; the residue alone was coke.

Reference had been made to the possibility of consuming smoke economically. He believed it to be physically impossible to consume smoke once formed, without loss, and the reasons were sufficiently obvious. If all the carbonaceous matter of the smoke was consumed, additional heat was, certainly, obtained, but by means which entailed more than a corresponding loss. This was proved both by experiment and by calculation; because if a certain quantity of oxygen was introduced into a furnace, a much greater quantity of nitrogen was introduced at the same time; 7 lbs. of nitrogen, in fact, for every 2 lbs. of oxygen. The nitrogen did not contribute to the combustion, but required to be itself heated, and therefore, it carried up the chimney a large quantity of the heat evolved from the combustion of the particles of smoke. But independently of that, there were no means of getting every particle of smoke which escaped unconsumed from the fire, to meet with the necessary particles of oxygen, unless a much larger quantity of air was introduced above the fire, than was theoretically necessary for the purpose. But in so doing, a correspondingly larger quantity of nitrogen was also introduced at the same moment, and thus the loss occasioned by heating the excess of oxygen and nitrogen, was much greater than the gain from utilising the heat of the carbonaceous particles of which the smoke consisted.

In making his experiments on the combustion of smoke, he had used a very perfect, self-acting apparatus applied to the boilers of a pumping engine, with the following results:—1st. When the engine was well fired, without the admission of air above the fire, the consumption of fuel was 100; but in this case, smoke was evolved in considerable quantity. 2nd. When the air was admitted in sufficient quantity to consume the smoke, without being shut off during any portion of the interval between the firings, the consumption of fuel became 120. 3rd. When the self-acting apparatus was brought into operation, to exclude the air so soon as smoke had

ceased to be emitted, then the consumption of fuel was reduced to 110.

The smallest additional consumption consequent on the consumption of the smoke, was about 10 per cent. The trial was frequently continued for several days together, without putting the air holes into operation, and then the consumption uniformly went down; when they were again called into action, the consumption as uniformly increased. He believed it was impossible to conduct experiments with greater care, or in a better manner, for determining the point in dispute between those who alleged, that the combustion of smoke was not, in a pecuniary sense, economical, and those who asserted the contrary. He thought the Paper had sufficiently shown, by the average of all the experiments related, that weight for weight, the consumption of coal in locomotives was greater than that of coke; and this result was confirmed by calculation, which proved, that such must, necessarily, be the case. It might, nevertheless, happen, that when the coke was consumed in an ill-adapted furnace and the coal was consumed in a well-adapted furnace, the contrary would result, and the experimenter would be led to an erroneous inference. Unless, however, 6 cwt. of coke could be delivered into a tender as cheaply as 7 cwt. of coal, when the smoke was not consumed, and about 8 cwt. when the smoke was consumed, the mere pecuniary economy must be on the side of the coal.

Mr. Yarrow,—through the Secretary,—observed, that it would appear from the Paper, that the system used upon the Great North of Scotland Railway was superior to the others, as regarded the amount of fuel consumed per mile, relatively to the gross load carried. To enable a proper comparison to be made, the Paper should give, in addition to the average speed per mile for the whole distance run, and the number of pounds of water evaporated by 1 lb. of coal, the greatest altitude surmounted in each case,—the average gradient,—and also its length. The experiments should be made on the same line of rails, with a train running at the same speed, and with the same stoppages. On the Scottish North Eastern Railway, for example, the speed of the passenger trains was about 35 miles per hour, whilst on the Great North of Scotland Railway, it did not exceed 25 miles per hour. The two cases did not, therefore, admit of comparison, as there was a greater amount of resistance, and consequently, more power was expended, on one of the lines, than on the other. Again, the speed of the goods trains, upon the Great North of Scotland Railway, was about 13 miles per hour, whereas upon the Caledonian Railway, it was about 20 miles per hour. On the Scottish North Eastern Railway, there was a rise of 340½ feet above the level of the terminal station, of which 234¼ feet had to be surmounted within a distance of

7 miles, the heaviest gradient on that part of the line being 1 in 91. There were various other steep gradients on the line; for instance, on another portion, 171½ feet had to be surmounted within a distance of 3½ miles.

Mr. ZERAH COLBURN,—through the Secretary,—presented the following observations on coal-burning locomotives in the United States:—

The circumstances affecting the substitution of coal for other fuel, were dissimilar in England and in the United States. So far as the question concerned English railway companies, it appeared to have already received a satisfactory solution; but it was still the subject of much discussion in America.

The cost of fuel on the lines in the Northern and Eastern States, averaged as much as 9*d.* per train mile. This fuel consisted, generally, of wood, which was sold by the 'cord' of 128 cubic feet, weighing about 1½ ton. One cord and a half, or rather more than 2 tons of good wood, would evaporate as much water as 1 ton of coal; and this quantity of wood sometimes cost as much as £2. 3*s.* The Directors of the Baltimore and Ohio Railroad Company, although their line intersected rich beds of semi-bituminous coal, stipulated, so long ago as 1831, that the engines to be constructed for their line should burn anthracite, so as not to emit any smoke. In 1837, the Beaver Meadow Railroad Company adopted the use of anthracite coal in their engines, which were of ordinary construction, and they still continued to employ it. In attempting, however, the general introduction of the same coal for long and heavy traffic, it was found, that although there was not any smoke, the steam was kept up with difficulty, and that the fire box and fire bars were quickly burnt out. Notwithstanding these objections to its use, anthracite was, in some cases, a cheaper fuel than wood. The Reading Railroad, the principal channel of the anthracite coal trade, was worked with this fuel, which was burned, however, with considerable waste. The fire box was very large, and was sometimes placed entirely behind the wheels of the engine, so as to obtain sufficient room for a grate, 5 feet in width. For the heavy goods engines, the grates were, generally, 7 feet in length and 3 feet 6 inches in width. The fire box was made, in most cases, of iron plates, $\frac{5}{16}$ths of an inch thick, but copper was sometimes used about the bottom. The tubes were of iron, 2¼ inches in diameter and 14 feet in length. The top of the fire box sloped off at an angle, and the fire was partially fed through a door in the roof. The hinder end of the fire box had no water space, being covered with a cast-iron plate, having two doors across its entire width, for feeding the fire, and two others below them, for raking out the fire bars. A few large openings were made in these doors, for the admission of air. The fire bars were always of cast iron, and were,

in the engines under notice, very heavy; the width between the bars was as much as $1\frac{1}{2}$ inch. They were cast in pairs, and each pair of bars had a shank, or stem, projecting behind the fire box: through a round hole in this shank, a bar was, occasionally, inserted, to shake the grate and to break up and dislodge the accumulated clinker. The ash pan was made with a water-tight bottom, and water was, occasionally, turned into it from the tender, to quench the hot coals and cinders dropping through, which would, otherwise, burn out the fire bars. A variable blast pipe was always applied, with a nozzle capable of being contracted from 18 to 6 square inches. With these arrangements, the reports of the company showed, that anthracite coal was burned at the average rate of 117 lbs. per mile, in engines weighing 28 tons, and drawing a gross load of 750 tons, at a speed of from 10 miles to 12 miles per hour, on a level. The evaporation of water was from $5\frac{1}{2}$ lbs. to 6 lbs. only, per lb. of coal. Mr. Colburn had conducted trials over the line in winter, when the consumption was 13,500 lbs. of coal, for 95 miles, or 142 lbs. per mile. The engines on this line had eight coupled wheels, 3 feet 7 inches in diameter; the diameter of the cylinders was 19 inches, and the stroke was 22 inches.

When the question of a general substitution of coal for wood was agitated, ten, or twelve years ago, among railway authorities in the United States, it was assumed, that only anthracite coal could be adopted, as smoke was thought to be inseparable from the use of bituminous coal. The locomotive superintendents of the various lines took out no patents, however, and the question was left open to inventors generally, most of whom appeared disposed to make the greatest possible changes in the ordinary form of boiler. Their plans were carried out by builders of locomotives, as well as by the different railway companies, and were worked with more, or less success. As some of these plans had, in this way, acquired considerable prominence in America, it might be desirable to give a brief description of them.

Phleger's boiler, as constructed in the engines made by Messrs. Richard Norris and Son, of Philadelphia, had a combustion chamber, formed by a deflecting water bridge in front of the tubes which, with the barrel of the boiler, were placed rather lower than usual. At first, the fire boxes of these boilers had close water bottoms, the air for combustion being forced in by a blower. The water bottom was still retained, although the air was allowed to enter in the usual way. A variable blast pipe, and a steam jet, or blower in the chimney, were provided, as in all American coal-burning locomotives.

In Dimpfel's boiler, the water was contained in the tubes, and also in a long annular water space, answering to the ordinary

cylindrical barrel of the boiler. The tubes were of iron, and of small diameter. They descended from the roof of the fire box, bending and extending thence to a water space at the forward end of the boiler. This plan had been extensively introduced by the Taunton Locomotive Manufacturing Company.

Boardman's boiler, as constructed in the engines made by Messrs. William Mason and Co., of Taunton, had upright tubes, through which the heat descended from a long combustion chamber, or flue, in the upper part of the boiler. This flue extended to and opened into the smoke box, but a plate was interposed, a few feet from the smoke box, the heat descending through the tubes next the fire box, and traversing an ash pan, before ascending the front tube.

Phleger's, Dimpfel's, and Boardman's boilers had been used, more, or less, for the last ten, or twelve years; but experimentally rather than practically. They had been made to burn bituminous as well as anthracite coal, and they were used on passenger as well as on goods trains. Each of these plans furnished considerable space for combustion, and in each, air was admitted in numerous fine streams over the fire. Each had obvious disadvantages, and neither was applicable to the existing stock. All were heavy and complicated, Boardman's boiler especially, and much of its weight was thrown upon the front wheels of the engine, where it was least desirable. The boiler occupied the whole space between the framing of the engine. This was not, however, an important objection, as, since 1854, all American locomotives had been made with outside cylinders, not only for the gauge of 4 feet 8½ inches, but also for those of 4 feet 10 inches, of 5 feet, of 5 feet 6 inches, and of 6 feet; the latter being the widest railway gauge in the United States. The staying of the flat sides of the Boardman boiler required great care, and with the stays fastened, as they had been, on the inside of the boiler, it was very difficult to replace them.

Within the last three, or four years, renewed attempts had been made, to adapt the existing stock of engines to the use of bituminous coal. The difficulties to be encountered, consisted in the large quantity of coal required to be burned in a given time, under an intense draught, and in the character of the coal itself, which produced a great quantity of clinker. American railways, generally, required more power to work them than was necessary on English lines. This arose from the steeper gradients and the sharper curves in the former, and from the inferior condition of the permanent way. The trains, although less frequent, and although running at a speed slower by one-third to one-fourth than the trains on English lines, were from one-third to one-fourth heavier. The engines, on the other hand, were not heavier, on

the average, than in England, nor had they more heating surface. They burned more fuel, however, and evaporated fully one-third more water, in a given time; a result depending on the strength of the draught. The average evaporation in American locomotives, might be taken at 120 cubic feet of water per hour. The 8 cwt., or 9 cwt. of coal necessary for this evaporation, had to be burned on a grate of which the area, generally, was not more than 14 square feet, giving a combustion of from 60 lbs. to 70 lbs. per square foot of grate per hour. The coal, besides being smoky and often sulphurous, was of that kind which quickly crusted over the top of the fire, and it, generally, made a large quantity of clinker: this was sometimes carried, by the strength of the draught, against the ends of the tubes, which thus became, in some cases, completely closed within half an hour after starting.

In December, 1856, Mr. George S. Griggs, of the Boston and Providence Railroad, introduced a fire-brick arch below the tubes, in the fire boxes of some of the engines of that line. With a few holes for the admission of air above the fire, this arch was found to improve the working of the fire box, when burning coal. A good deal of fine coal was carried through the tubes, and the ordinary spark-arrester of the wood-burning engines was, therefore, retained. By carefully selecting the best coal in the market, Mr. Griggs was enabled to use the ordinary fire bars; but on other lines, with coal producing more clinker, bars had been adopted which could be moved while the engine was running. In some cases, the whole fire grate had been formed of stout chains, suspended across the fire box; the flexibility of this arrangement had an important influence in keeping the fire clear of clinker. It had been also found, that with coal producing much clinker, the air opening of the grate required to be materially diminished, so as to localise the draught over a comparatively small area, and thus, by intensifying the combustion, to thoroughly fuse the clinker, which then ran off like glass. On the Iowa Central Railroad, the grates of the coal-burning engines were, at one time, covered with fire brick, so as to leave exposed only about 2 square feet of the original surface of the bars, and of this area less than 1 square foot was used as an air opening. This arrangement was found to work well, with coal producing much clinker; and, notwithstanding the diminution in the area of the air opening, as much coal was burned, and as much steam was made as before. In other coal-burning locomotives, it was now usual to close up from 12 inches to 30 inches of the front ends of the fire bars, and in many cases, the 'dead plate,' as it was called, extended along the sides of the fire box, reducing the area of the grated portion of the fire box bottom to 4, or 5 square feet, of which less than one-half was air opening. Upon the dead plate, the coal

became partially coked before entering into active combustion. The fire was fed, generally, with small quantities of coal, frequently and equally applied. More recently, perforated door plates and air distributors, the latter set up within the fire box, had been extensively adopted. It was only rarely, that the spark arrester of the wood-burning engines was dispensed with, in burning coal. This apparatus intercepted considerable quantities of fine coal, which, under a strong draught, would otherwise have been thrown out at the top of the chimney.

The circumstances affecting American railway traffic were so different from those which existed in England, that it would hardly convey an accurate idea of the success of these plans, to give the consumption of coal per train mile. It might be said, however, that they worked with tolerable freedom from smoke, that they generally afforded a good command of steam, and that they gave an evaporation of from $6\frac{3}{4}$ lbs. to $8\frac{1}{2}$ lbs. of water per lb. of coal.

Mr. Longridge said, he had already given the results of some carefully-conducted experiments, showing a decided advantage in the evaporative powers of Garesfield coal, over the coke made from that coal. He should not have again referred to those results, had it not been contended, that theoretically, as well as practically, coke was superior in heating power to the coal from which it was made. It was not possible to determine, theoretically, the precise temperature arising from the combustion of fuel, owing to ignorance of the specific heats of the products of combustion at high temperatures, and also of the latent heat of some of the generated gases which were, probably, emitted in a solid form in a body, like coal. So far, however, as theory would go, calculation[1] showed, and his experience confirmed the fact, that the

[1] Heat generated by 1 lb. of Coal.

		lbs.		Units of Heat.
Carbon		0·8152	× 14,500 =	11,820
Hydrogen	0·0522			
Less the amount to combine with the oxygen in the coal	0·0077 =	0·0445	× 62,032 =	2,760
Sulphur		0·0115	× 4,152 =	48
Total heat generated				14,628

Products of Combustion, multiplied by the Specific Heat.

	lbs.	Specific heat.		
Carbonic acid	2·989 ×	·217 =	0·6486	
Sulphurous acid gas	0·023 ×	·240 =	0·0055	
Nitrogen	8·912 ×	·245 =	2·1834	
Steam	0·470 ×	·475 =	0·0223	
Ash	0·046 ×	·200 =	0·0092	= 2·860

Consequently, the resulting temperature $= \frac{14,628}{2·869} = 5,098°$.

[Proceeding

temperature resulting from the combustion of 1 lb. of Hartley coal, was greater than that resulting from 1 lb. of the coke made therefrom, in the proportion of 5,098° to 4,695°, or of 100 to 92; and the proportion would be still higher in a coal like the Garesfield, containing more hydrogen.

It had been urged, against the economical use of bituminous coal, that to prevent the smoke arising from its use, it was necessary to introduce into the furnace, an extra quantity of air, which carried off a large amount of heat. Now the extra quantity of air required for perfect combustion, was not nearly so large as was generally thought. He had made direct experiments to ascertain the fact, with an apparatus so arranged, that the quantity of air actually passing through the furnace could be accurately measured, separating, moreover, what passed through the bars from what was admitted above the fire surface. The result was, that to burn 1 lb. of Hartley coal perfectly, it required 149·4 cubic feet of air at 60° and 30 inches of mercury.[1] Now it was found, that

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Proceeding in the same manner with the coke, consisting of:—

Carbon	94 per cent.
Ash	6 „

HEAT GENERATED BY 1 lb. OF COKE.

Carbon . . . . $0·94 \times 14,500 = 13,630$

PRODUCTS OF COMBUSTION, MULTIPLIED BY THE SPECIFIC HEAT.

	lbs.	Specific heat.		
Carbonic acid . . .	3·415 ×	·217 =	0·7411	
Nitrogen	8·774 ×	·245 =	2·1496	
Ash	0·060 ×	·200 =	0·0120	= 2·9027

$$\text{Consequently, the resulting temperature} = \frac{13,630}{2·9027} = 4,695°.$$

This, in the case of coal, was found = 5,098°;
Therefore, 1 lb. of coal : 1 lb. of coke : : 5,098° : 4,695
: : 100 : 92 nearly.

[1] QUANTITY OF AIR REQUIRED FOR THE PERFECT COMBUSTION OF 1 lb. OF HARTLEY COAL.

Composition of 1 lb. of Coal.

Oxygen	0·0615
Hydrogen	0·0522
Nitrogen	0·0150
Sulphur	0·0115
Carbon	0·8152
Ash	0·0446

Oxygen required for the Perfect Combustion of the above.

Carbon	$0·8152 \times \frac{16}{6} = 2·1738$ lbs.
Hydrogen	$0·0522 \times 8 = 0·4178$
Sulphur	$0·0115 \times \frac{16}{16} = 0·0115$
	2·6031
Deduct oxygen in coal	0·0615
Oxygen required from the air . .	2·5416 lbs.

Hence, the weight of air will be $2·5416 \times \frac{36}{8} = 11·4372$ lbs.; from which the volume of 60° and 30 inches of mercury is found = 149·4 cubic feet.

with the ordinary system of stoking and making a dense smoke, the quantity of air which passed through the furnace, was only 100 cubic feet per lb. of coal burnt, showing conclusively, that a great deal of carbonic oxide was passing off with the products of combustion. When smoke was entirely prevented, by air admitted above the fire, the quantity was found to be 158 cubic feet, being only 9 cubic feet above what was necessary for the perfect combustion of the coal. The temperature of the up-take was also ascertained under the two circumstances, with and without the additional quantity of air. When 100 cubic feet of air per lb. of coal passed through, the temperature was 448°; with 158 cubic feet of air passing through, the temperature was 480°.[1] To the boiler in which these experiments were tried, there were adapted means of regulating the quantity of air admitted above the grate. In another case, with no air except that which passed through the bars, and with much smoke, the temperature in the chimney was 600°. With one aperture open, the temperature was 625°; with two apertures, it was 633°; with three, it was 638°; and with five, it fell to 620°; showing again, that up to a certain point, the admission of air did not decrease, but rather increased, the temperature. He thought these results were conclusive proofs; first, that it was not necessary to introduce an excessive quantity of air, above what was chemically required for combustion; and secondly that the result of the admission of air, in such quantity as was required to prevent smoke, was to increase the temperature of the chimney, and to decrease the consumption of fuel.

This had, however, been fully confirmed by experiments made by order of the Admiralty, in March and April, 1859, on board the 'Bustler,' to ascertain the advantages, or otherwise, of the use of ventilating doors for the prevention of smoke. Those made in March, showed an advantage of 16½ per cent., and in April,

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[1] Results of Ten Experiments on Hartley Coal, made at Elswick, in July, 1857, by J. A. Longridge, Sir William Armstrong, and Dr. Richardson.

Weight of Coal burnt, per Square Foot of Fire grate per Hour, in lbs.	Water Evaporated from 212° by each lb. of Coal, in lbs.	Total quantity of Water Evaporated, per Hour, in Cubic Feet.	Quantity of Air used per lb. of Coal burnt, in Cubic Feet.	Temperature of Smoke Box.	Remarks.
17·34	12·27	56·71	158*	480°	No Smoke.
21·00	10·06	56·01	100	448	Much Smoke.

* Of this, about 88 cubic feet were admitted through the doors, and 70 cubic feet through the fire bars.

The quantity of air required for the perfect combustion of 1 lb. of this coal, is 149·4 cubic feet, at 60° Fahrenheit, and 30 inches of mercury, as shown in the preceding note; (pages 576–7).

of not less than 21 per cent. of coal per indicated H.P., in favour of the use of the ventilating doors; thus fully bearing out the results arrived at by Mr. Longridge, Sir William Armstrong, and Dr. Richardson, in the Elswick experiments. The following Table was extracted from a return to the House of Commons, "of the Results of Experiments which have been made by the Admiralty on board any of Her Majesty's ships, with a view to the consumption of smoke, combined with the economy of fuel, within the last eighteen months," and which was ordered by the House to be printed on the 18th of April, 1860:—

Date of Trial.	Draught of Water. Forward	Draught of Water. Aft.	No. of Experiments.	No. of Runs in each.	Duration of Experiment.	Total Coal burnt.	Mean Indicated H.P.	Coal per H.P per Hour.	Mean Revolutions.	Mean Pressure.	Mean Speed.
1859.	Ft. in.	Ft. In.			Hours.	lbs.		lbs.	Per Min.	lbs. sq. in.	Knots per Hour.
10 Mar.	7 1	6 8	5	4	4	6,326	244·9	6·45	23·10	16·92	8·879
18 Mar.	6 11	6 9	5	4	4	7,410	241·4	7·67	23·20	16·60	8·964
15 Apr.	6 11	7 2	5	4	4	5,600	245·4	5·70	22·34	17·53	8·467
19 Apr.	6 11	7 2	5	4	4	7,100	246·6	7·20	22·80	17·26	8·793

The experiments on the 10th of March and on the 15th of April, were made with the ventilating doors open, and firing at the sides of each furnace alternately; on the 18th of March and the 19th of April, these doors were closed. Bituminous, north country coal was used in the first pair of experiments. On the 10th of March, smoke was only visible when the fires were urged and stirred; it was then of a light brown colour, and in moderate quantity. On the 18th of March, the smoke was dense and black during the trial. In the second pair of experiments, the coal was of good quality, and in a fair condition as to size. On the 15th of April, only a light brown smoke issued from the chimney, and for a considerable portion of the time, there was no smoke. The mercury in the barometer, on this occasion, stood at 29·1 inches, and there was a strong gale of wind on the beam, so that it was with difficulty the vessel was kept in a straight course, consequently showing a reduced speed. On the 19th of April, the weather was calm, the mercury in the barometer stood at 29·6 inches, and much black smoke was emitted.

Mr. Hawksley did not doubt, that the experiments made at Elswick, had been as carefully carried out, as experiments of that nature could be, and he concurred in the results, but he could satisfactorily explain them. If there was an insufficient quantity of air below the fuel, carbonic acid was generated, and as it progressed, it decomposed into carbonic oxide, an uninflammable gas, which required fresh air to be introduced, in order to re-convert it

into carbonic acid gas. That action always took place when the fire was deep. It was evident, that in the cases mentioned, carbonic oxide was formed, because, when the air was admitted over the fire, the temperature was increased. Those experiments, therefore, although perfectly well made, were not experiments which settled the matter in dispute. The furnace was not in that particular condition which was necessary for burning the particular fuel placed upon it, and his observations had reference to coal and coke, burnt in furnaces constructed for the purpose. In his own experiments, perfect combustion was obtained in both cases, and as he had already stated, the result was, without entering into the commercial part of the question, that, weight for weight, coke was superior to the coal from which it was made. He believed the reason of it to be, that the coal contained moisture and other matters which did not contribute, during its combustion, to the production of heat.

Mr. E. A. Cowper,—through the Secretary,—remarked, that when burning coke, carbonic oxide was always formed in greater, or less quantities, even with a moderately thin fire, and it was interesting to know the area of opening for air which was considered sufficient, per square foot of grate, to properly consume it. The coke, as well as the coal, ought to be burnt in the best manner, in order to institute a fair comparison. He was much gratified, that the decisive experiments upon the quantity of air actually used for the consumption of fuel, had proved it to be nearly the amount theoretically required, as it confirmed him in a conviction he had long entertained, that Count Rumford and others were wrong in stating, that twice the theoretical quantity of air had always to be passed through the fire, to effect proper combustion. Now it was quite certain, that with any ordinary boiler fire, some air must be passed over the fuel, in order to prevent smoke; for it was, practically, impossible to keep a fire sufficiently thin to pass enough air through it, for burning all the gases and carbon, as then the grate would frequently be partially uncovered. There was a decided economy in burning the carbonic oxide and hydrogen, by the introduction of air in proper quantities, so as to prevent smoke, though the advantage was not very great. In numerous experiments which he had made with different sorts of coal and coke, he had found, that good oven coke was more valuable, weight for weight, than good coal, when each was burnt in the best manner, and that good gas coke was, generally, equal to coal. He believed, that the steam coals for the navy ranked, to a great extent, in proportion to the per-centage of carbon in them.

With regard to the water heater, he mentioned, that about the year 1848, he had seen a similar contrivance at Renfrew, in Scotland, and that it answered very well, giving the feedwater a tem-

perature of nearly 212°. It consisted of a box, into one side of which the steam entered, passing out at the top, whilst the water to be heated came in at the top, and fell through the steam, being entirely encompassed and in direct contact with it; he believed the same system had been employed at Mr. Hague's, and at many other places.

The plan of admitting air through hollow stays into the fire boxes of locomotives, as proposed by Mr. Hall, of Basford, had been revived by Mr. M'Connell, with the addition of jets of steam supplied from the boiler, to drive in the air. The advantage of being able to forcibly drive powerful jets of air into the gases was, no doubt, very great, as the jets would penetrate the gases in a similar manner to the blast in a blast furnace; and the opportunity it gave of preventing all vacuum, or draught in the fire box, when standing at a station, was also of great utility. He did not think, that it was clearly stated in the Paper, that all the plans had the means of regulating the quantity of air admitted, so that in none of them was there, necessarily, a large quantity of air entering at all times. In the most recent plan, that of the long spout, or shovel, there were on many lines, proper sliding doors in front, so that the driver could easily regulate the quantity of air, by touching the doors with his foot, or hand. It was an exceedingly simple and excellent contrivance, but did not, like the tubular stays and steam jets, give the power of introducing air when the engine was standing.

Mr. C. Greaves,—through the Secretary,—thinking it desirable, that the progress in the economy of fuel, so far as those occupied in the locomotive branch of engineering had succeeded in carrying it, should be made known, would bring forward some results derived from the experience of stationary engines, to assist the discussion, so far as there might be any analogy between the different circumstances.

The philosophy of the production of smoke appeared to have been succinctly stated in the Paper. The hydrogenous compounds in coal were those most readily extracted by heat. The hydrogen did not leave the coal without bringing with it a portion of carbon, but notwithstanding their union, the hydrogen was still the more easily inflammable of the two. Neither of them would burn without the presence of atmospheric air; if, therefore, there was only a limited quantity of air, the hydrogen was burnt without the carbon and it formed smoke. It was, however, practically found, that it required less heat to consume the hydrogen, than to burn away the solid carbonaceous portions of the coal. There were, consequently, two methods of preventing the occurrence of smoke; either to force, or to admit to the inflaming hydrogen, a sufficient quantity of air to render the combustion of

both it and its gasified carbon complete, and to continue this only so long as it was necessary; or to delay the explosion of the hydrogen and gaseous carbon, so that the ordinary flow of air, admitted through the bar, for the combustion of the solid carbon, should suffice for the combustion of the hydrogenous compounds. Now the latter process could not be easily effected in locomotive fires, but in land and stationary boilers, it was not difficult, with the cheapest small coal, so to damp the coal and to lay it on the fire quickly in a thick heap, that the charge of coal should ignite only from the face in contact with the previous fire. The combustion of the gaseous part was slackened to the rate of the admission of the air from the fire grate, and a smokeless process was maintained. This was not a theory, for he had now, for some years, practised the plau, at the rate of 4,000 tons per annum, with perfect success as to smoke, and with excellent results as to efficiency, as the following Table would show:—

TABLE showing the amount of fuel employed in four sets of boilers, the comparative proportion of small coal contained in it, (the rest being gas coke,) and the evaporative power obtained per lb., at an average temperature of 80°; during the first half of the year 1859:—

	Fuel, in Cwt.	Per Centage of Small Coal.	Water Evaporated, in lbs.
No. 1 . .	16,259	92·97	7·91
„ 2 . .	14,248	89·71	8·32
„ 3 . .	4,265	90·00	8·16
„ 4 . .	4,578	82·98	8·61
„ 5 . .	5,701	88·68	7·59

The following were the results during the second half of the year 1859:—

No. 1 . .	17,814	91·63	7·81
„ 2 . .	12,186	84·03	8·00
„ 3 . .	7,435	86·75	8·13
„ 4 . .	8,083	88·35	7·82
„ 5 . .	1,367	85·73	8·18

The average rate of combustion of the whole, was about $6\frac{1}{4}$ lbs. per square foot of grate per hour.

The relative calorific power of coal and coke had been, similarly, the subject of patient investigation, and reliable results had been obtained from trials extending over a long period. Taking the small of the best coal as a standard of comparison, the use of gas coke gave a result superior to it, of 14 per cent. The combustion of those coals usually called steam coals, as Holywell Main, West Hartley, South Peareth, &c., only produced an effi-

ciency from 5 to 10 per cent. more than that of small coal, which, on an average, cost about 11*s.* 6*d.* per ton. The steam coal was burnt without any attempt to avoid smoke.

He regretted, that it should ever have been stated, that coke would do more work than the coal from which it was made. His experience had, unequivocally, proved, that under boilers commonly called Cornish, worked at high pressure, at a moderate rate of thorough combustion and with every advantage, one ton of coke would perform more work than one ton of such coal as that from which coal gas was made. Indeed it would, he thought, be generally admitted, that the calorific power of that part of the coal, which produced the hydro-carbons, or the gaseous matter, was lower than the calorific power of the carbon, which burned by direct combustion with oxygen. Both coal and coke, as ordinarily burnt, contained about 7 per cent. of waste; and coal, burnt as coal, appeared to afford 65 per cent. of solid combustible matter, and 28 per cent. of combustible gas. Now picked and clean coke would evaporate ten and a half times its weight of water, at a temperature of 80°; therefore 0·65 lb. of the pure carbon in 1 lb. of coal would evaporate 7·34 lbs. of water. But 1 lb. of coal afforded 4·46 feet of gas, and 100 feet of gas only evaporated 28·3 lbs. of water, at which rate, 4·46 feet would evaporate 1·26 lb.; and admitting, that a larger proportion of carbon was burnt in a gaseous form with an open fire, than with retorts, the result was 7·34 lbs. and 1·26 lb., which with an addition of, say 0·65 lb., made the total efficiency of good coal 9·25 lbs., as compared with 10·5 lbs., the efficiency of good coke, at a temperature of 80° Fahrenheit. The relative values of 9·25 lbs. for coal and 10·5 lbs. for coke, on special trials, with care and exactness, were about equivalent to 8 lbs. for coal, and 9 lbs. for coke, in ordinary practice and with long trials; and from his own experience, he adopted the latter quantities as their relative value by weight. Generally speaking, all trials of relative value, by the cost of the fuels, were much more favourable to coal. There were, unfortunately, no good Reports of the calorific power of gas, used in a practical way; a good series of experiments would be extremely valuable.

He had the highest opinion of the plan advocated by the Author, the control of the acting force, being, under the peculiar and varying conditions in which locomotives were placed, the point to be aimed at; increasing the admission of air up to the irregular requirements of the coal gases, rather than delaying the explosion of gases to the minimum rate of admission of air, through the ordinary fire grate.

Mr. D. K. Clark said, the result of his experience was, that so far as locomotive engines were concerned, a saving of coal to

the extent of 18 per cent. had been effected, by properly consuming the smoke. If coal was burnt in a locomotive, without any provision for the admission of air above the fuel, certain unconsumed gases were sent through the chimney. In 1856, he had made a comparison of the cost of coke and coal, and he found, that coke cost, upon an average, 18*s*. 2*d*. per ton, and coal 8*s*. 7*d*. per ton; the recent introduction of coal-burning in locomotives had slightly reduced the price of the coke. The prices at Crewe, were 14*s*. 11*d*. for coke, and 7*s*. 10*d*. for coal. On the Oxford, Worcester, and Wolverhampton Line it was 21*s*. for coke and 10*s*. 6*d*. for coal, and on the Midland Railway 20*s*. for coke and 9*s*. for coal. On the North Eastern Railway the price of coking coal was not more than 6*s*. per ton, its conversion into coke would raise it to 9*s*., and allowing 1*s*. per ton for labour and the maintenance of furnaces, the total cost would be 10*s*. per ton. The difference in price as compared with coal, was thus only about 4*s*. per ton, scarcely sufficient to induce the company to use the latter.

In reply to remarks by Mr. G. Berkley,—that the coke was made from the refuse of the coal, and by Mr. T. E. Harrison, that a large quantity of coke was supplied to the North Eastern Railway Company, at 9*s*. per ton,—Mr. Clark said, that the information he received was, that the coking coal was sold at 6*s*. per ton. He had not been able to give in detail, the particulars of Mr. Jenkins's apparatus, as employed upon the Lancashire and Yorkshire Railway, but he had understood, that the air was admitted to the furnace, through rows of tubes, at different levels, varying from each other as much as 12 inches, in their height above the grate; if the lower rows were covered by the fuel, the air so introduced below the level of the fuel did not contribute towards the prevention of smoke. As regarded the comparative performances of Mr. Jenkins's apparatus and that of the Author, on the Brighton Railway, the two systems were applied in the same passenger engine No. 89, and by the Official Report of Mr. Craven, the locomotive superintendent, the respective results were as he had stated them in the Paper. The number of miles run by the engine under Mr. Jenkins's system was 1,949, with a consumption of coal of 33·6 lbs. per mile; and under his own system, on the same duty, 878 miles, with a consumption of 29·3 lbs. of coal per mile. It should be observed, that the longer mileage run in the first case, was a favourable circumstance in the trial of Mr. Jenkins's system, as the excessive consumption of fuel incidental to the trial of new systems, during the first few days, was arranged over a greater number of miles in his case, than in Mr. Clark's.

He might state, that the greater part of the information demanded by Mr. Yarrow, for the purpose of enabling a proper com-

parison to be made, was given in the Tables; that it was of no use to give the altitudes simply, unless the particulars of the inclines, and the length of the trips were also given; that the average speed of the goods trains on the Caledonian Railway, deduced from the service time tables, was 12 miles per hour, not 20 miles per hour, and on the Great North of Scotland Railway, it was, by the time tables, $14\frac{1}{4}$ miles per hour, not 13 miles; further, that the average distance run between stopping stations was, on the Caledonian, $6\frac{3}{4}$ miles, and on the Great North of Scotland, 4 miles.

May 8, 1860.

GEORGE PARKER BIDDER, President, in the Chair.

No. 1,025.—"On Indian Railways: with a Description of the Great Indian Peninsula Railway."[1] By JAMES JOHN BERKLEY, M. Inst. C.E.

THE importance of Railways in British India is more correctly represented by the extent of the country, its population, and the well-known richness and variety of its produce, which constitute the source of all railway traffic, whether internal, or foreign, than by its commerce. This distinction in favour of railway prospects is illustrated to a remarkable degree, by the statistics of India; for though its commerce in the year 1858-59, amounted only to £60,219,660 sterling, its population is estimated at 185,000,000, of which 132,000,000 are in the British dominions. Its area is 1,484,367 square miles; and its principal producing districts are as rich and extensive as the possessions of any civilised nation, which has made the growth of commerce an important element of its policy. The cause of the commerce of India having continued so incommensurate with the resources of the country, which has been under British rule for nearly a century, may be chiefly assigned to the want of proper communications. Its roads, with a few recent exceptions, have been little better than bad tracks, fit only for native conveyances, which have been contrived merely for rough usage and the slowest travelling. The great physical barriers have been left unsurmounted, except by these rude means, and the traffic across them has been obstructed by almost every possible kind of impediment; while the rivers have, in only a few instances, been made navigable. The usual conveyances of the country have been carts, elephants, camels, pack-bullocks, and asses.

Indian railways will not, therefore, as in England, be the substitution of a perfect system of conveyance, for other convenient means, at the demand of a prosperous nation; but they

[1] The discussion upon this Paper extended over portions of two evenings, but an abstract of the whole is given consecutively.

will be, at least in many districts, the first introduction of any communication whatever, adapted for the requirements of the country. Their effects in the creation and development of traffic must, consequently, be very considerable. It is not, however, from these considerations alone, that the subject of Indian railways may claim the attention of the Institution of Civil Engineers. It is rather in the remoteness of the country, and the novelty of its physical character, in the peculiarities of its labouring classes, of its soil and climate, and of the materials it produces, that matter worthy of being placed upon record, may be found.

In the year 1849, the Indian Government took the first decided step, towards the establishment of a system of railways in India, by entering into arrangements with the East Indian and the Great Indian Peninsula Railway Companies, for the construction of railroads in the Presidencies of Bengal and Bombay. Since that date the formation of 4,821 miles has been sanctioned; 636 miles have been opened for traffic; 765 miles are expected to be opened in 1860, and 864 miles in 1861. The estimated capital required to complete these lines, amounts to £52,450,000; of which sum the expenditure of £34,133,300 has been sanctioned by the Indian Government, and £27,129,622, has already been subscribed.

The arrangements under which the Indian railways, now in course of construction, are established, consist of a Government guarantee, as the means of raising the requisite capital; the agency of Incorporated Companies, to design, execute, and manage them; and Government supervision to define the projects, and control the proceedings and expenditure.

The terms of the contract between the Government and the Companies, may be thus briefly stated:—

The Government guarantees, for ninety-nine years, a dividend of $4\frac{1}{2}$ to 5 per cent. upon the estimated cost of the railway. They supply, free of cost, all the land requisite for the line and the stations.

They have power of approval, or disapproval of all lines laid out, and of their estimated cost; and they also exercise a general control over the affairs of the Company.

They appoint a Director, who has, with one, or two exceptions, a general veto on the proceedings. The cash is paid into the Government Treasury; accounts are kept as directed, and are always accessible.

They regulate the tolls, time tables, &c.; and stipulate for mails being carried free, as well as for officers, soldiers and Government stores being conveyed on advantageous terms.

When lines pay more than the guaranteed dividend, one-half

the surplus is to be retained. until the arrears of interest paid by Government have been repaid; and terms are made for the purchase of lines, rolling stock, &c. under certain conditions, previous to the termination of ninety-nine years, when, if the Railway Company have given no notice for sale thereof as arranged, the property will pass into the hands of Government.

These terms and the system they constitute, may, so far as they have been brought into operation, be pronounced to have been successful; although attended with some disadvantages. On the one hand, the following beneficial results may be assigned to the guarantee system. The requisite capital has always been forthcoming with remarkable facility, and Indian railway stock has occupied a firm position in public confidence; the finished portions of the undertakings have been made at a comparatively low mileage cost; the land has been provided with unusual despatch; there has been scarcely any litigation; (this enormous item of English railway expenditure has, in fact, been almost eliminated from the accounts;) the public traffic has been carried on, for seven years, with perfect safety; and lastly, Indian railways stand well in public estimation, and will, most probably, continue to do so, in consequence of the thorough and independent scrutiny to which they are constantly subject.

On the other hand, it must be acknowledged, that these many and important advantages have not been obtained, without some countervailing sacrifice. There has, undoubtedly, been great loss of time, which has occasioned serious inconvenience to the public, and especially to the State, during the late mutiny. In the earlier operations of the Companies, supervision was exercised with an unnecessary degree of minuteness, which was one cause of misunderstanding and delay. It must, however, be remembered, that railway practice was new to the controlling authorities, and that they had to acquire experience, to satisfy themselves of the capabilities of the Companies' agents, to store up precedents for future guidance, and to note many details, to which peculiar value attached, so long as Indian railways were regarded only as experimental. The most protracted delays, however, arose from the multifarious authorities, whose opinions had to be brought into unanimity, before any important business could be proceeded with, and from the great quantity of official labour, which was involved by every reference to so many widely-scattered tribunals. There was a Local Committee of Railway Directors, or a Managing Agent; the Local Government; the London Board of Directors; the Supreme Government; the Honourable Court of Directors; and the Board of Control. Amongst so many authorities, dif-

ferences of opinion frequently arose, discussion and correspondence were freely had recourse to, and unfortunately, the more urgent and important the subject, the greater was the delay. Ten years have elapsed, since the Great Indian Peninsula Railway Company was in a position to commence operations; yet only a small proportion of that period has been occupied in the construction of any of the several sections of the line, and in every case, considerable time was spent in preliminaries. The periods occupied in constructing those sections have varied, from only one year and a quarter to four years; and it is, therefore, evident, that the slow progress has not been occasioned by a want of energy in constructing, but of promptitude in deciding upon the projects, and of simultaneousness in carrying them out to the full extent to which they were needed by the country. It is solely to the working of the guarantee system, that these defects can, it is thought, be attributed. Recently, however, the transaction of railway business has been simplified and improved, for less delay than was formerly experienced, is now found to attend it, and an effectual co-operation generally subsists between the several Companies and their supervising authorities.

It has been asserted, that the interest accruing from delay in constructing the Indian railways, will seriously affect economy. Though this may be a sound argument for despatch, it is an exaggeration of the actual evil; for the capital being called up only by instalments, as the various sections of the line come forward for construction, and the time spent in making them not being unusually long, interest is rarely allowed to accumulate for any lengthened period. A similar charge for interest on unproductive capital has really stood to the debit of all railways, at the date of their completion; and it would be unfair to charge Indian railways with unusual excess under this head, except in those instances where delay has occurred between the raising of capital, and the commencement of active operations upon the lines for which it was provided. There is, however, another item of expenditure attaching to the guarantee system, which ought not to be passed unnoticed, the disbursements which the Local and Home Governments have had to incur, in the performance of those special functions which appertain to them under the supervising system.

It has been considered important, that uniformity should be established, as far as possible, on Indian railways; the following standard dimensions have, therefore, been adopted. The uniform gauge is 5 feet 6 inches, and the minimum clear width between the tracks is 6 feet. The minimum clear distance of the platform wall from the rail, is 2 feet 6 inches, and the projection of the nosing of the platform, not more than 3 inches. The minimum clear height for all over-openings above the rails, in the

centre of each line, is 14 feet 6 inches. The breadth from centre to centre of the buffers is 6 feet 5 inches, and the height of the centre of the buffers above the rail is 3 feet 6 inches, for all the rolling stock. The goods-loading gauge for interchange of traffic is to be settled to a pattern. In the passenger carriages, the extreme width of the body is 8 feet 6 inches; of the roof, 10 feet 6 inches; and of the steps, 10 feet. The maximum length between the centres of the wheels of both carriages and waggons is 11 feet, and they are to have spring buffers and draw springs at both ends. The minimum diameter of the turn-tables is 15 feet, and the engine and tender are to turn on tables, 40 feet in diameter.

Thus far attention has been directed to the subject of Indian Railways in general.

The Great Indian Peninsula Railway will now form the special subject of this communication. The principal lines of this railway are proposed to extend from the port and city of Bombay, to join the East Indian Line at Jubbulpore on the north-east, with a long branch to Nagpore, and to join the Madras Line on the south-east, at, or about the River Kristna.

Bombay, the western terminus to which the trunk lines and all others connected with the undertaking, converge, is a justly celebrated port. Its population now numbers about 700,000, consisting of Europeans and Asiatics of all castes and races. The advantages of its situation, in the centre of the western coast of the peninsula of India, and of its safe and capacious harbour, are obvious; and these, as well as the recent preponderance of trade, distinguish it as the commercial capital of India. It is the depôt of the Indian navy, and the number of square-rigged vessels and native craft which entered and departed from the harbour in 1858-59, amounted to

1,200	square-rigged vessels and steamers . .	892,218	tons
10,873	native craft	460,714	„
12,073	Totals . . .	1,352,932	„

It exported, in 1859, 206,915,874 lbs. of cotton, valued at £3,957,639 sterling. The produce of the customs has risen from £3,024,000 to £6,169,200 per annum, more than double, in only five years. Its commerce in merchandise and treasure amount, for 1858-59, to a total of £34,332,423, the imports being £18,381,541, and the exports, £15,950,882, or £9,000,000 more than the whole foreign commerce of India, in the year 1848.

The chief imports are;—cotton and woollen goods, machinery,

metals, wine, spirits and malt liquors, military and naval stores, railway materials, ivory, spices, silk, sugar, tea, coffee, tobacco, horses, drugs and dyes, fruits, precious stones, books and stationery, grain, seed, oil, timber, ice, apparel and treasure. These are derived from the United Kingdom, Africa, China, Penang, Singapore, the Straits of Malacca, the Persian Gulf, Suez, Calcutta, Malabar, North America, the Arabian Gulf, Batavia and Java, Ceylon, France, the Mauritius, Aden, Cutch and Guzerat.

The chief exports are:—cotton, hides and skins, oils, saltpetre, seeds, Cashmere shawls, wool, opium, coffee, dyes, sugar, tea, grain, provisions, precious stones, beads, metals, spices, salt and fruits; and they are generally consigned to the same places whence the imports are derived.

Bombay is already an established field for industrial enterprise, and many large manufacturing establishments are in active operation. It now stands in urgent need of the following additional accommodation:—new docks,—enlarged custom-house premises,—extended wharfage and quay accommodation, with covered sheds,—large warehouses,—and an improved system of landing cargo.

So crowded, indeed, is the city, that one of the most difficult matters to be decided is, where to find a commodious site for the railway terminus, which has, hitherto, been only of a temporary character. There has, in the course of the last few years, been an extraordinary rise in wages, varying from 25 to 100 per cent., and a corresponding increase in the prices of native materials requisite for public works. These and other signs of prosperity it is impossible to call in question, and they clearly indicate a great and rapid improvement.

With this port and metropolis as a western terminus, the Great Indian Peninsula Railway will command a portion of the great traffic of the north-western provinces of India; the opium fields of Malwa; the grain and seed provinces of the valley of the Nerbudda; the vast cotton fields of Berar, of the Nizam's dominions and of Sholapore; and the trans-peninsular traffic from Calcutta and Madras. The Syhadree Mountains, or, as they are commonly called, the Ghauts, intercept the channel of communication for this vast and important traffic. They lie parallel to the coast, from which they are distant about 30 miles, and, in a range of about 100 miles, there are only two main roads by which wheeled traffic can cross them; the Agra road up the Thul Ghaut, and the Poonah and Calcutta road up the Bhore Ghaut. The rest of the passes are rough tracks, fit only for the use of pack-bullocks.

When regarded as a means of conveyance for a rich and extensive tract of country, capable of sending to a central port like Bombay, a large amount of produce, to supply the demands of distant competing markets, the principal characteristics of the existing

roads and means of transport in the Bombay Presidency are;—extreme slowness, only about twelve miles per day,—uncontrollable irregularity,—great cost of conveyance, amounting to $3\frac{1}{4}d.$ to $4\frac{1}{2}d.$ per ton, per mile,—physical obstructions, and the crowded condition of the roads,—the short duration of the favourable season for conveyance,—the limited extent of the present means of carriage,—and the damage to goods, and losses by theft and from bad weather, upon the journey.

These difficulties particularly affect the very important export of cotton, the beneficial growth, package, conveyance, and sale of which, are much influenced by the want of the facilities which will be afforded by the railways in course of construction. This railway system will operate most beneficially upon the whole of the commercial transactions relative to cotton. It will give facilities for local superintendence, and thus help to bring about the improvement of cultivation, to promote greater cleanliness in the subsequent process, to neutralise the influence of the Brahmins, and to prevent fraud by the middlemen. It will free commerce from loss and damage on the journey, by either preventing, or giving compensation for them. It will establish one regular continuous journey from the depôts to Bombay, and will insure perfect independence of the seasons, so far, at least, as regards conveyance. It will afford the Bombay merchants great advantages for shipment and freight to England, and it will give more independence to this species of commerce, by balancing the return loads. The aggregate benefits of the railway system, and its legitimate consequences upon the cotton supply of Western India, have been estimated at as much as 2*d.* per lb., and there is little doubt, that a considerable part of this economy will be effected in the course of a few years, by its various beneficial operations upon that important branch of Indian commerce.

The first section undertaken by the Great Indian Peninsula Railway Company, was that from Bombay to Callian, 33 miles, with a branch to Mahim of $1\frac{1}{2}$ mile; it was called the 'Experimental Line.' It was begun by Messrs. Faviell and Fowler in February, 1851, and was finished by them, in conjunction with Messrs. Wythes and Jackson, and Mr. Jamsetjee Dorabjee, a Parsee, in April, 1854. The portion from Bombay to Tannah, a distance of 20 miles, was the first railway opened in India for public traffic, which event took place on the 16th of April, 1853. From Bombay to Callian, a double line of rails has been laid. Its steepest gradient is 1 in 150, and the radius of the sharpest curve is 40 chains. The Bombay terminus is at Boree Bunder, having the advantage of a quay frontage to the harbour, and although it occupies an area of 19 acres, it is already overcrowded. The site not being permanent, all the buildings are of

a temporary character. The Company's depôt for working the lines is situated at Bycullah, about 2 miles from the terminus. It covers an area of $18\frac{3}{4}$ acres, and contains steam sheds, erecting and fitting shops, smithies, iron and brass foundries, saw mill, carriage-repairing and waggon-building sheds, stores, warehouses, coke shed, a timber-preserving establishment, offices, and workmen's and engine-drivers' dwelling-houses.

The principal works upon the Experimental Line are the crossing of the Sion Marsh, which is effected by an embankment; the crossing of the arm of the sea from the island of Salsette to the Concan, comprising two viaducts, the length, respectively, of 111 yards and 193 yards, in the latter of which there is an opening for navigation, of 84 feet, spanned by wrought-iron plate girders; beyond this, there are two tunnels of the respective lengths of 103 yards and 115 yards. The railway is protected by post and rail fences, and prickly-pear and cactus hedges. The station buildings are of masonry. The permanent way is chiefly laid with transverse wooden sleepers, and 6 miles of it with iron pot-sleepers. The rails, which are of the double T form, weigh 84 lbs. per lineal yard, as far as Tannah; beyond which place, they weigh only 65 lbs. and 68 lbs. per yard. The lighter rails extend along the whole of the Company's main lines, except the two Ghaut Inclines, on which will be laid rails of 85 lbs. per yard. From Callian diverge,—the South-Eastern Extension to Poonah and Sholapore, and its proposed prolongation to the River Kristna and the Madras Railway,—and the North-Eastern Extension to Nassick and Jubbulpore, to join the East Indian Railway from Calcutta, by which a communication will also be effected with the North-Western Provinces of India.

The first section of the South-Eastern Extension is from Callian to Campoolee, at the foot of the Bhore Ghaut mail-road. It is $37\frac{3}{4}$ miles in length, of which $30\frac{1}{4}$ miles, to the foot of the railway incline, are permanent, the remainder having been designed for temporary use, until the Ghaut Incline was opened. This portion of the railway was begun by Mr. Jamsetjee Dorabjee in 1854, and was finished in 1856. It has been constructed for a double line, but only one road has been laid. Its ruling gradient is 1 in 115 on the permanent, and 1 in 85 on the temporary portion. The radius of its sharpest curve is 40 chains. It contains no work of any special character, but it is remarkable for the extraordinary floods and rapid torrents to which it is exposed on both sides. The bridges and culverts are built of rubble masonry, with coursed facework; and in one, or two instances, cast-iron girders were made use of. The average cost of this section, exclusive of rolling stock, was only £4,500 per mile.

Bhore Ghaut Incline.—Four years were spent in preliminary surveys of this incline, and in laying out and preparing cross sections, to the number of about two thousand, and perhaps, the most difficult that have ever been taken. Four years more have already expired since the contractor commenced operations upon it. The works were begun by Mr. Faviell in January, 1856, and taken up in November, 1859, by Mr. S. Tredwell, whose melancholy death within a month of his arrival in India, many members of the profession must sincerely lament. It is expected to be finished about three years hence. It is 15 miles 68 chains in length, and the total rise is 1,831 feet. Its average gradient is 1 in 48. The steepest gradients are 1 in 37 and 1 in 40, for a total length of 9 miles and 44 chains; 1 in 37 extends in one length for 1 mile 10 chains, and 1 in 40 for 5 miles 6 chains. Short lengths of level gradients and of 1 in 330 are introduced into this incline, to facilitate the ascent of the engine. The radii of the curves upon it range from 15 chains to 80 chains; but as much as 12 miles 45 chains have a radius of more than 30 chains, and 5 miles 33 chains are straight. It comprises twenty-five tunnels, of a total length of 3,585 yards. The longest is 437 yards; and the longest without a shaft, which is carried through a mountain of basalt, is 346 yards. There are eight viaducts of a total length of 987 yards. The two largest are 168 yards long, and respectively, 163 feet and 160 feet above the foundations. The viaducts are being built, up to the surface of the ground, of solid block in course masonry, and above, of block in course facework, strongly tied through by header bonds of block in course, to the internal work of sound rubble, and with coursed rubble arches. The contract also comprises a large quantity of retaining walls. The total quantity of cutting, chiefly rock, amounts, by calculation, to 1,263,102 cubic yards. The maximum depth of cutting is 70 feet, and the greatest contents, 75,000 cubic yards of trap rock. The embankments amount to 1,849,934 cubic yards, the maximum height being 74 feet; and the greatest contents are 209,000, and 263,000 cubic yards. The slopes average about 1½ to 1. There are twenty-three bridges of various spans, from 7 feet to 30 feet, and sixty culverts from 2 feet to 6 feet wide. The rails weigh 85 lbs. per yard, and are laid with fish joints, with small cast-iron saddles under the joints, resting upon longitudinal planks, the ends of which bear upon, and are secured by fang bolts to transverse wooden sleepers. The estimated cost of this incline is £750,000. The upper 2 miles, from Khandalla to Lanowlee, with gradients of 1 in 40 and 1 in 50, were opened on the 14th of June, 1858, and have since been worked with safety and regularity.

At the eleventh mile, the incline is divided into two banks, by

what is called a reversing station. This subdivision, however, was not adopted for the purpose of making two banks of the incline, but of increasing the length of the base, in order to flatten the gradient and to reach a higher level, where it encountered the great features of the Ghaut margin, near Khandalla. Without the necessary expedient of the reversing station, the practicability of changing the direction of the line would have been confined to making curves of small radius; but with the device of the reversing station, the direction was altered at a very acute angle, by means of points and crossings. In consequence of its adoption, the incline is prolonged by nearly the difference between the length of the two sides of an acute-angled triangle, and that of its base.

The limits of this communication will not admit of the proper treatment of this subject, nor of that of the Thul Ghaut Incline, either of which alone demands a separate Paper.

The following Table presents a comparison between the Bhore Ghaut, and the Giovi and Sömmering Inclines:—

Name of Incline.	Length.	Total Ascent.	Average Gradient.	Maximum Gradient.	Sharpest Curves.	Total length of Tunnelling.
	Miles.	Feet.				Miles.
Giovi Incline . . .	6	889	1 in 36	1 in 29	20 chains radius.	2·55
Sömmering Incline:—						
Ascent from Payerback to Sömmering	$13\frac{1}{4}$	1,325	1 in 47	1 in 40	30 curves of 10 chains radius, and 38 curves of 14 chains radius.	2·66
Descent from Sömmering to Murzzuschlag . . .	$8\frac{1}{3}$	705	1 in 50	1 in 50		
Bhore Ghaut Incline	$15\frac{7}{8}$	1,831	1 in 48	1 in 37	1 of 15, and 2 of 20 chains radius.	1·44

The peculiar difficulties upon this incline are the unfavourable nature of the hot and rainy seasons; the fatal epidemics which dismay and disperse the people employed upon it; the lofty and precipitous character of the ground, which impedes the haulage of materials and harasses all who are engaged in the operations; the extensive and sudden slips upon the mountain sides; the extreme hardness and solidity of the rocks; the scarcity of water; and the want of necessaries and comforts for the men.

Setting aside all consideration of the design, the Bhore Ghaut Incline is, in point of construction, a stupendous mass of works, crowded upon an unhealthy, desolate, and inaccessible mountain scarp; and it can only be completed by a display from all parties employed, of resolute endurance and unflagging energy.

The next section of the South-Eastern Extension is from Lanowlee, the summit of the Bhore Ghaut Incline, to Poonah and Sholapore, and is 205½ miles in length. The first 42 miles were begun by Mr. Faviell in January, 1856, and were finished in June, 1858. The remaining 163¾ miles were commenced by Mr. J. Bray, in March, 1856, and 143 miles were completed on the 27th of December, 1859. Its engineering character is very similar to that of the Concan section. Its ruling gradient is 1 in 132, and the radius of its sharpest curve is 40 chains. The cuttings are in trap rock, moorum, and soil; and the embankments are chiefly composed of soil and moorum. There are twenty-two viaducts, three hundred and fifty-nine bridges, and four hundred and fifty-four culverts, all built of substantial masonry. The largest works are the viaducts over the Beema, 441 yards long and 60 feet high, consisting of twenty-eight segmental arches 40 feet in span, with a flood stream 46 feet deep, and rock foundations, the cost of which was £24,246; and that over the River Seena, 190 yards long, 54 feet high, consisting of twelve segmental arches 40 feet in span, with a flood stream 41 feet deep, and foundations partly in rock and partly on hard clay. The fences are dry rubble walls, and cast-iron posts and iron-wire rails. One peculiarity of this district is the violence and suddenness of the floods, which descend with scarcely an hour's notice, and gather into torrents on spots upon which there is no trace, or warning of any stream. In the uncommenced portion of the South-Eastern Extension, from Sholapore to the junction with the Madras Line, in the Raichore district, there will be two very large viaducts over the Rivers Beema and Kristna. Upon the South-Eastern Extension large quantities of cotton and country produce are now carried, and it is evident, that an immense traffic must soon be accommodated. The earthwork has been executed for a single line, and the viaducts and bridges for a double line.

Returning to Callian, the first section of the North-Eastern Extension, which there diverges towards Jubbulpore and Calcutta, is from Callian to Kussarah, 26 miles, gradually climbing, by steep gradients, of which a great portion are 1 in 100, the flank of a long mountain spur, which projects from the Ghaut range, and divides the valley of the Basta on the south, from the Wyturnee on the north. This section is full of heavy work; but to obtain even such a line, demanded a long and minute study of the rugged and jungle-covered district. The works have been executed by Mr. Jamsetjee Dorabjee. The radius of the sharpest curve is 30 chains. It contains 520,493 yards of cutting, chiefly trap and basaltic rock, and 1,353,317 cubic yards of embankment. It comprises four viaducts, of which the two largest are, respec-

tively, 124 yards and 143 yards long, and 127 feet and 122 feet high; forty-four bridges from 7 feet to 30 feet in span, and one hundred and seventeen culverts. By means of this section, 849 feet of the ascent have been surmounted to the summit of the Ghaut, and thus the altitude to be overcome by the Thul Ghaut Incline is reduced to only 972 feet.

THUL GHAUT INCLINE.—The Thul Ghaut Incline extends from the village of Kussarah to Egutpoora, and is in course of construction by Messrs. Wythes and Jackson. It is 9½ miles in length, and has a total ascent of 972 feet. At the end of 3¾ miles there is a reversing station, similar to that upon the Bhore Ghaut Incline, by which the base was lengthened, the gradient flattened, and the incline divided into two banks. The steepest gradient is 1 in 37, for a length of 4 miles 30 chains; and the same introduction of a level portion is adopted here as on the Bhore Ghaut. The radius of the curves ranges from 17 chains to 100 chains; but of 7 miles 12 chains the radius exceeds 30 chains, and 3 miles 28 chains are straight. There are thirteen tunnels, of a total length of 2,652 yards. The longest are, one of 474 yards, in black basalt, with two shafts, and another of 483 yards, without a shaft, in greenstone. There are six viaducts, of a total length of 741 yards, the largest of which are, respectively, 144 yards and 250 yards long, and 83 feet and 182 feet high. The latter is designed for three spans of triangular iron girders measuring 150 feet, with a pair of semicircular abutment arches measuring 40 feet at each end. There are fifteen bridges, of which the span varies from 7 feet to 30 feet, and sixty-two culverts. The cost of the incline will be about £450,000. The preliminary surveys and studies occupied four years, and the works were commenced in October, 1857.

The next section of the North-Eastern Extension runs from the summit of the Thul Ghaut Incline, at Egutpoora, by Nassick, across the fertile valley of the Godavery, and the Indyhadree range of mountains, along Khandeish to Bhosawul, the point of junction with the Oomrawuttee and Nagpore Branch. The character of this line is very similar to the corresponding section of the South-Eastern Extension, from the Bhore Ghaut to Sholapore, and the nature of the earthwork is much the same. The principal works upon it are:—a viaduct over the Godavery, 145 yards in length, consisting of nine arches 40 feet in span, with a flood stream 36 feet deep, and foundations upon rock, excavated through sand; the Kadoo Viaduct, 242 yards in length, with fifteen arches 40 feet in span; the Munnair Viaduct, with five openings spanned by triangular iron girders, and two pairs of abutment

arches; and the Waugoor Viaduct, with ten openings also spanned by triangular iron girders. This section contains twenty viaducts, two hundred and seventy-nine bridges, and four hundred and thirty-five culverts. It was commenced by Messrs. Wythes and Jackson, in October, 1857.

The last section of the North-Eastern Extension runs from Bhosawul to Jubbulpoor. It is 328 miles in length, and was contracted for by Messrs. Duckett and Stead, in January, 1859. As the operations are in a preliminary state, it is only necessary to notice the two very large viaducts over the Rivers Taptee and Nerbudda. The Taptee Viaduct is 875 yards long, consisting of five openings of 138 feet and fourteen openings of 60 feet, and twenty arches 40 feet in span, with a flood stream 70 feet in depth, and foundations upon rock. The Nerbudda Viaduct will be about 387 yards long, 100 feet high, with a flood stream 90 feet deep.

The Oomrawuttee and Nagpore Branch is about 263 miles in length. It was let to Messrs. Lee, Watson, and Aiton, who are now just commencing operations. As the line has not yet been entirely staked out, no details can, at present, be given; but its general character is known to be favourable, and the works are light. The largest works will be the viaducts over the Rivers Nalgunge and Wurdah.

There is no tunnel beyond the Ghauts, upon any of the lines now under construction, comprising a length of 782 miles.

The general style of design for these trunk lines is derived from the model of the late Mr. Robert Stephenson's English railways, with such modifications as were rendered necessary by special circumstances. The propriety of adopting a line of a character so substantial and durable, has been called in question by parties who profess to be strict economists, having a thorough knowledge of India. It has been argued by them, that the American system, or even tramways, would have been far more suitable and politic; but the following considerations will show, that this opinion is unsound. The Great Indian Peninsula Railway runs parallel to the main communications of Western India, and must, therefore, not only be adapted for the conveyance of the present large traffic of the country, but be capable of meeting the demands of that immense increase which such facilities of transport are intended, and cannot fail, to generate. It may be admitted, that long before India has been covered with such a labyrinth of lines as figure upon the map of America, cases will frequently present themselves where a cheaper style of construction will be appropriate. But an agricultural line, which might be economical and convenient in the

plains of America, and even in many provinces of India where cultivation may only become profitable when a railway is completed, would be insufficient along those main routes, where 100,000 tons per annum of bulky and valuable goods, and a large travelling population already stand in need of conveyance, and where the increase of the traffic is beyond all definite calculation. Unsubstantial lines of railway, costly to work and to maintain, would also be inappropriate for the conveyance of an extensive traffic across the ravines, and through the basaltic mountains of the Ghauts; and in the Presidency of Bombay they would prove an utter failure, as they could never withstand the four months' deluge of the monsoon, and the torrents that annually rush down from the mountains and flood the country.

The following fundamental points are observed and carried out with the greatest practicable economy and despatch, in the completion of the railway system. The character of the main lines is plain, substantial, and durable, and such as will provide for the regular and expeditious conveyance of a heavy and increasing traffic in goods, and the accommodation of a great number of passengers, at a moderate working cost, and at a reasonable expenditure in maintenance.

The geological nature of the country is volcanic; the hills and mountains consist of trap rock and laterite, a kind of ferruginous clay, so called from its frequent resemblance to brick. Granite hills protrude in the southern Mahratta country below Sholapore. The trap is of various sorts, more, or less, earthy, or crystalline, and the hills have, almost invariably, either a crest, or axis of basalt; their surface is bare, or covered with what is called in India, moorum. The basalt, sometimes highly porphyritic, is nodular, rectangular, tabular, and columnar. Moorum is of a reddish, or gray colour, and is, no doubt, decomposed rock of a very earthy nature; in the cuttings, it is found both hard and soft. In the valleys, there is a great depth of vegetable soil.

As favouring engineering operations, the destructible nature of the slopes of cuttings and embankments made of the black soil; the facility of excavating moorum, its firmness for slopes and embankments, and frequent suitability for ballast; the advantage of having rock foundations for the crossings of rivers and streams, and also that of making tunnels without either lining, or faces; and the fine quality of the stone for building purposes and the facilities of quarrying it, are worthy of special notice. As a set-off to these advantages, there are the extreme hardness of the black basalt, which renders progress both tardy and expensive, and the precipitous altitude of the mountains, which, in many cases, prevents the sinking of shafts, and thus limits the mining of tunnels to the two faces only.

Among the geological features, the existence of large quantities of kunkur, a variety of fresh-water limestone, and the want of good brick earth, must be mentioned.

In excavating the Ghauts, a valuable store of zeolites have been exposed; they are found in the bubbles, or cavities of the rocks. This class of minerals is peculiar, as they contain a great quantity of water, which evaporates with more, or less rapidity in each species, thus rendering them perishable when exposed to the atmosphere. Among them, the mesolite, poonalite, apophylite, stilbite, and laumonite, are the most abundant. Professor Maskelyne has already placed some fine specimens in the British Museum, and their number will, no doubt, shortly be increased. They are not only beautiful, but rare, and are esteemed, in museums, as second only to the specimens of gold from Australia and California.

The physical geography of the districts of Western India traversed by the Great Indian Peninsula lines, may be thus briefly described. First, the plain of the Concan, elevated very little above the level of the sea; then the abrupt scarp of the Syhadree Mountains, the least altitude of which above the sea, is about 2,200 feet; and beyond that, the plain of the Deccan on the South-Eastern Extension, gradually sloping down towards the eastern coast of India: whilst upon the North-Eastern Extension, the country presents the bold features of the Rivers Taptee and Nerbudda, with three parallel chains of mountains called the Indyhadree, the Santpoora, and the Vyndhya ranges. The altitudes of various known spots along the railway are:—

Altitudes.	Height above High-water Mark at Bombay.
	Feet.
Level of the ground at the Bombay Terminus . . .	11
Ditto at the Callian Station	16
Foot of the Bhore Ghaut Incline at Padusdhurree .	196
Top of ditto at Lanowlee . . .	2,027
Level of the ground at Poonah Station	1,811
Ditto at Sholapore Station	1,481
Ditto at Kristna, near Narrainpoor . .	1,291
Foot of the Thul Ghaut Incline at Egutpoora . . .	940
Top of ditto	1,912
Level of the ground at Jubbulpore	1,218
Ditto at Oomrawuttee	1,134
Ditto at Nagpore	997

The physical character of the country is less favourable to the Railway Engineer than it might appear, in consequence of the extraordinary quantity of rain which falls upon the western coast during the monsoon, a period of four months from June to September. The line of the Ghauts is the axis of these rains, and

the rivers and streams which rise in it are either dry, or stagnant, during the fine weather, and become deep and violent torrents during the monsoon. The height of known floods, where the railway crosses some of the principal rivers, varies from 25 feet at the Waldhur, to about 70 feet at the Taptee, and about 90 feet at the Nerbudda. Extreme difficulty has been experienced in ascertaining the maximum heights of floods, not merely in the rivers, but in most of the numerous streams which it was necessary to cross. There is nothing upon the ground to indicate them, and the information obtained by careful and extensive inquiry has, generally, been of the most inconsistent nature. Some idea of this difficulty may be conveyed by the fact, that in the year 1837, the River Taptee, where the railway crosses it, rose 30 feet above the highest level it has since attained.

The following Table exhibits the amount of rainfall during the year 1858, at different places upon and near the western coast:—

	Inches.		Inches.
Malligaum	19	Poorundhur	41
Dhoolia	19	Baroda	41
Poonah	21	Alibag	80
Gogo	24	Bhewndy	80
Ahmednuggur	28	Bombay	85
Nassick	29	Tannah	91
Surat	30	Rutnagherry	106
Sholapore	31	Panwell	107
Suttara	31	Narel	121
Dharwar	31	Khandalla	156
Belgaum	36	Matheran	255
Kolapore	39	Mahableshwar	265

The railway materials procurable in India are, iron, coal, timber, stone, bricks, lime, gunpowder, and ballast. Indian coal and iron are very seldom seen in the Bombay market. In many parts of the Nerbudda valley, coal exists of excellent quality and in great abundance, and it lies in a favourable position for being worked. Iron ore, too, abounds, especially on the right bank of the Nerbudda. The principal mines of the district are those at Tenderkaira, near Nursingpoor, about ten miles from the Great Indian Peninsula Line. They are now worked in the rudest fashion, but the iron produced is of excellent quality. There are furnaces also at Paneghur and Gosulpoor, close to which the railway passes, and although the iron is deemed inferior to that of Tenderkaira, it is good, and forms an article of export from those towns. Valuable iron mines also exist at Poonassa and Chandghur, and there are five mines within twenty miles of Jubbulpore. Productive, however, as these may hereafter prove, it is evident, that active and successful operations in the manufacture of Indian iron, or the supply of coal, depend more upon the completion of

railway communications, than the railway depends upon a local supply of these materials.

The various kinds of wood procurable for railway purposes are of unusually good quality. The properties of some which have already been extensively used, are represented in the following statement, the specimens experimented upon being 7 feet in length, by 2 inches square in section, a size adopted in previous experiments:—

No. of Experiments.	Names of the Woods.	Specific gravity in Ounces.	Breaking weight in Pounds.	Ultimate deflexion in Inches.	Cost per Cubic Foot.	
					s.	d.
5	Northern Teak . . .	880	672	5 75	5	0
3	Southern Teak . . .	768	1,012	6·87	6	0
2	Blackwood	896	924	6·75	8	0
4	Khair	1,168	966	4·00	2	6
3	Errool	1,008	718	4·50	2	6
3	Red Eyne	1,088	559	2·50	2	6
2	Bibla	896	560	5·62	2	6
3	Poon	624	425	3·62	..	
3	Kullum	656	569	6·12	2	0
3	Hedoo	624	630	4·25	2	0
2	Jungle Teak	656	537	3·00	2	0

It has not been found necessary to make use of timber in the permanent bridges. The following woods have been successfully converted into sleepers:—teak, blackwood, khair, errool, and red eyne.

The cost of a sleeper 9 feet 9 inches long, 10 inches wide, and $4\frac{1}{2}$ inches thick, has varied from 4*s*. to 7*s*. $7\frac{1}{2}$*d*., and the average price has been about 6*s*. It was, at first, feared, that wooden sleepers could not be used in India, on account of the ravages of the white ants, but it is a curious and important fact, that although they have been very often seen, eating the sapwood of sleepers lying on the surface of the ground by the side of the railway, those laid in the ballast of the permanent road have not been injured by them.

The whole of the rolling stock, except the engines and tenders, and the first and second-class and composite carriages, is chiefly built of teak in the Company's workshops, and is strong and durable.

Excellent building stone is generally procurable, and is easily quarried. Various qualities are met with suitable either for hammer, or chisel dressing, whilst the sharpness of the rough blocks and stones adapt them for strong rubble masonry. It is of the usual hard and compact nature of the trappite, or green-stone class, and when properly selected in the quarries, it is never found to be injured by exposure to the weather. The large size of the blocks has been found most useful, for the foundations of

machinery in the Company's shops, where sound stones, containing 44 cubic feet, have been laid. Good brick earth is rarely to be met with, and the fuel for making the bricks, which commonly consists of grain husks, is very sparingly used. Consequently, although bricks are cheap and abundant, they are seldom of suitable quality for railway works. Moderately good bricks have been, occasionally, procured and used in arches, but to obtain them, a proportion of only 23 per cent. has been selected from the best native kilns. The price ranges from 10*s*. to 24*s*. per thousand. The former rate is for small-sized bricks of inferior quality; the latter are good bricks made of the English size. The lime is of a remarkably fine quality, and is hydraulic. In making chunam, or mortar, one part of lime is mixed with two parts of sand. It sets rapidly, so as to give immediate stability to the work, and continues to do so for twelve, or fifteen months, until it becomes as hard as the rock itself. Saltpetre and charcoal being easily procurable in the country, gunpowder is largely manufactured. It is very strong and suitable for blasting, and costs, when made upon the spot, about £34 per ton. The ballast consists of sand, broken stones, gray moorum, and nodular basalt.

The Bombay and district markets have greatly varied, and have been sometimes found unfavourable for extensive dealings. The railway demands being unusually large, have, occasionally, been met by a combination of native merchants, who find it easy to establish a monopoly amongst themselves, and to work it to their profit. This movement has been defeated by a variety of expedients, such as obtaining supplies from the Government stores, procuring the articles direct from the depôt, making them by the Company's own agency, or importing them from England. The result, however, has been a great augmentation of prices, and considerable irregularity in obtaining supplies. It is one remarkable feature in Indian railway practice, that a very large, and certainly the most expensive, portion of the materials, have to be supplied from England; a circumstance which not only affects the cost, but also the progress of the works. Experience has already established the fact, that the period requisite for finishing a line for the use of public traffic in the interior of India, is not determined by the local execution of the works, but is dependent upon the delivery along the line of the permanent-way materials, station machinery, and rolling stock, which have to be procured in England, shipped to Bombay, and thence transported to the various districts of the railway.

During the year 1858-9, the shipments to Bombay of permanent-way materials, rolling stock, machinery, and miscellaneous stores, amounted to 66,937 tons, against 51,386 tons shipped in the previous year. The average sum paid in the year, for freight,

was £2. 0*s*. 9*d*. per ton of dead weight; the lowest rate, 20*s*. per ton, having been paid in July, 1858, and the highest rate, 60*s*. per ton, in June, 1859; an increase of 29 per cent. upon the average rate of the previous year.

Many of the articles sent from England have been specially designed for Indian use, their main principles being strength, simplicity, and durability, with as much regard to facility of transport as those essential properties would admit.

Greaves's iron sleepers, as used by Mr. Robert Stephenson in Egypt, have been laid on portions of the Great Indian Peninsula Railway, not, however, on account of any objections to the wooden sleepers procured in the country, but because of the difficulty of obtaining a sufficient and timely supply of them. A store of English iron sleepers has, therefore, been found convenient for meeting emergencies, and experience has shown, that they are handy for transport, that they are quickly and well laid by native labourers, and that they make a good and durable permanent way. A few consignments of creosoted sleepers have also been despatched to Bombay. They proved to be more expensive than Indian wooden sleepers, and were also very liable to split during exposure, between the time of landing and their being laid down. A complete apparatus has been sent out, and fitted in Bombay, for dressing timber with corrosive sublimate; as the climate has proved favourable for kyanising. The Indian sleepers which have been dressed, have absorbed about $3\frac{1}{4}$ gallons of corrosive sublimate; and the cost, including haulage, has been 1*s*. 6*d*. per sleeper.

An iron goods-shed and an iron booking-office were supplied from England, in 1853. Their comparative dearness may, perhaps, be compensated for, by their durability and cheapness in repairing, and they are convenient for removal; but, on account of their great heat, they have been unsuccessful, notwithstanding well-devised means of ventilation. In future, any iron buildings imported from England, should consist merely of framework, the large surfaces in the sides and upon the roof being afterwards filled in with non-conducting Indian materials.

Native labour by which these works have been executed, is cheap, but very inferior to that of England. Nearly one hundred thousand men have been employed upon the Great Indian Peninsula Railway lines at the same time, and as many as forty-two thousand upon the Bhore Ghaut Incline, which is $15\frac{3}{4}$ miles in length. This great force has not been collected without considerable trouble; it is not entirely supplied by the local districts, but is gathered from distant sources. Labourers sometimes tramp for work as in England, and on the same work may be seen men from Lucknow, Guzerat, and Sattara. The wants of the works have, however, been supplied by unusual exertions in sending

messengers in all directions, and by making advances to muccadums, or gangers, upon a promise to join the work with bodies of men at the proper season. Country artisans and skilled labourers have their own methods of doing work, but are capable of improvement and are not averse to change their practice. For operations requiring physical force, the low-caste natives who eat flesh and drink spirits, are the best; but for all the better kinds of workmanship, masonry, bricklaying, carpentry, for instance, the higher castes surpass them. Miners are, on the whole, the best class in the country. The natives strictly observe their caste regulations, yet will readily fall into an organisation upon particular works, to which they will faithfully adhere, and in which they are by no means devoid of interest. Although they cling closely to their gangers, they will attach themselves to those European inspectors who treat them kindly. The effective work of almost every individual labourer in India, falls far short of the result obtained in England. This is a disadvantage upon works, the dimensions, and proper mode of execution of which, limit the number of men that can be employed at one time, because the rate of progress is proportionally diminished. The fine season of eight months is favourable for Indian railway operations, but on the other hand, fatal epidemics, such as cholera and fever, often break out, and the labourers are, generally, of such a feeble constitution, and so badly provided with shelter and clothing, that they speedily succumb to those diseases, and the benefits of the fine weather are, thereby, temporarily lost. They work under the immediate control of a ganger, or muccadum, and the various gangs, under a maistry, or native foreman; and the whole under the inspection of a European overseer of works, by whom interpreters are also usually required. Not only men, but women and children, are employed upon Indian works; and thus, although the wages of the individual are small, the earnings of his family are by no means inconsiderable. The present rates of wages, per day, of the several classes of native labourers are:—

	s.	d.
Native Maistries, or Foremen of Masonry, Brickwork, or Carpentry	2	6
Masons	1	9
Bricklayers	1	3
Carpenters	1	6
Smiths	2	0
Miners (a very large class)	0	9
Excavators	0	7½
Labourers	0	6

These rates are very low as compared with English wages, but allowing for the comparatively small effectiveness of Indian

labour, the following may be safely taken as the relative cost of each kind of labour, in England and the Bombay Presidency.

Classes of Labour.	Proportion of Work done by each.		Relative cost of Labour in each Country.	
	England.	Bombay.	England.	Bombay.
Masons	$2\frac{1}{2}$	1	$1\frac{1}{3}$	1
Bricklayers	4	1	1	1
Carpenters	3	1	$1\frac{1}{4}$	1
Miners.	3	1	$2\frac{1}{4}$	1
Excavators	4	1	$1\frac{1}{2}$	1
Labourers	$3\frac{1}{2}$	1	$1\frac{5}{8}$	1

In examining this Table, it should be borne in mind, that the comparison is between simple labour only, and that it does not represent the cost of finished work; for the economy in favour of India suffers, from the expense of obtaining the powerful aid of English appliances, from defective and clumsy methods, and from a variety of drawbacks and disadvantages peculiar to native customs. Strikes, although of rare occurrence, have, occasionally, taken place, and the truck system, commonly discountenanced at home, is beneficial in India.

The whole of the Great Indian Peninsula Railway has been successfully executed by contract. This adoption of the English example has elicited a bona fide competition in the public market, and has effected remarkable economy in the construction of the lines. It has insured the execution of the works with considerable despatch, for although the allotted periods have been short, all the contracts have been completed with a fair degree of punctuality. It has enabled the Company to draw largely and advantageously upon the resources of the country, both in labour and materials, without suddenly, or unduly affecting the public markets, which must have been the case, had the Railway Company conducted its own enormous transactions, instead of easing the extraordinary demand by dividing it among so many contracting agents, with such different connections and modes of negociating business. It has, probably, been more successful than any other system, in making use of European mechanical appliances for the execution of railway works, and in effecting an extensive and powerful organisation of native labour, improved and controlled by European superintendence and co-operation; it has, moreover, introduced a class of wealthy and useful men, who have formed the strongest link in India that could be established,—the conviction that it affords them a profitable field of enterprise for the employment of their capital, experience, and agency.

A very large engineering establishment, containing some most

competent and rising young Engineers, has been created for the performance of the required professional duties, and considering the severity of the service in this climate, where they have had to execute extensive works of a novel description, with untrained labour, it is remarkable how little change, or casualty has occurred among the Company's officers, many of whom have, during many years, acquired very valuable experience.

The introduction of the contract system into India on a wide scale, is a very important effect of railway enterprise, and its advantage cannot be long confined to railway construction, for it will prove the best and most effectual agency for the execution of the many large public works, which will, ere long, be projected. Speaking generally, the European contractors have, as a rule, been more successful than natives, because the native tenders for the principal contracts have, usually, been either too high, or unreasonably low, so that, looking to their inexperience of such works, it has not often been thought desirable to take advantage of their agency, in the construction of the main lines. There has, however, been one remarkable instance of the employment of native enterprise; a Parsee contractor, Mr. Jamsetjee Dorabjee, has executed four main-line contracts as satisfactorily, as expeditiously, and as cheaply, as any of the European firms, and is now about completing his fifth, which comprises some of the heaviest works on the lines.

In other respects, native agency has been employed and encouraged, as much as possible. The Company's Engineers, Assistant Engineers, and Surveyors are generally Europeans, but one native Engineer has won his way to the office of Assistant Engineer, and has skilfully discharged its duties for three years. In the office establishment of draftsmen, accountants, and clerks, all the situations have been held by natives. As inspectors of work, natives have been chiefly employed. As district inspectors of the line, when opened, native agency is already partially adopted, and is, by encouragement, gradually becoming more useful. The principle to be kept in view is, that only by means of European and native co-operation, can the great railway undertakings which are required in the Bombay Presidency, be accomplished with due despatch. European skill, experience, and management, are of primary importance, but native agency has proved much more valuable and efficient than was anticipated, and will, undoubtedly, be found capable of considerable and rapid growth, if it is adopted without prejudice, and is treated with equity; and if native employés of all classes are stimulated to improve themselves, by the assurance of their gradual advancement, according to merit.

In the methods of executing the works two objects have to be

kept in view; first, to turn those of the natives to the best account; and secondly, to introduce English appliances where it can be done with advantage. It has not always been obvious which of these measures would, under the circumstances, be the more effectual, and experience has taught, that some Indian modes of doing work, which seemed barbarous and clumsy, were the cheapest and quickest means which could be employed.

Tunnels may be said to be an entirely new description of work in Western India, and the whole process, except blasting and excavation, was unknown to native workmen. In the earliest tunnels, where the top was heavy, it was found, at first, impossible to keep native miners in the heading, and the timbering was done chiefly by Europeans and one, or two Parsee carpenters, and the arch was keyed in by the former alone. Native miners use the churn drill, with which they are very handy, and they have sometimes been brought to work in pairs with the hammer, and strike with dexterity. They will work hard in close contact, and in the foulest atmosphere. They are careless in blasting operations, and consequently, the loss of life has been considerable; miners have been seen to fire a shot with a bamboo, and lie upon the ground while it exploded.

In building viaducts and bridges, there is a mixture of appliances and operations. In pumping foundations, English pumps only are sometimes used, but they are often aided by the native methods of the Persian wheel and by the Mahratta moat, a leather bag containing about 35 gallons of water, which is lowered and lifted over a pulley by bullock power. The natives also have various hand devices for scooping, or baling water from the bridge pits, all of which are occasionally resorted to. Where water has to be brought, it is carried in leather bags called puckals, laden in pairs on bullocks' backs. In some districts, it is thus conveyed more than two miles, to the masonry.

In staging and scaffolding it is only rarely, and in very large works, that the English example has been followed, nor are crabs and derricks so often met with as might be expected. The reason for this is afforded by experience, which has taught how cheap and expeditious it sometimes is, to use the native process. The bamboo coolies, or carriers of heavy weights, will lift their loads up the roughest staging, and the masons and labourers require but little help, to find their way to the work at the top of the highest piers. The centering commonly adopted in the country, was to fill up the arch with stone and earth, and to shape the top to the form of the soffit, or at other times, to use almost a forest of jungle wood in scaffolding a rough centre. For these, centres of English construction have invariably been substituted, with, as may be conceived, immense advantage to the work.

The native sawyers always work in pairs, even in the smallest jobs. The sawing is so inferior, that a great deal of adzing is requisite, and much of the work that would be planed in England, is turned out roughly with the adze in Bombay. In planing there is the same peculiarity of working in pairs; carpenters squat to their work, and it is with extreme difficulty, that a few of them have been brought to stand to a bench. It is remarkable to observe how freely they call in the aid of their feet; a carpenter may be seen resting his weight upon one foot, and cleaning his axe with the sole of the other.

In making embankments, the Hindoo custom of carrying the earth in baskets upon the head, is, owing to the cheapness of land for side cuttings, found more economical than waggon roads with long 'leads', and, judging by the result, it is attended with very little sacrifice of despatch. Within one month, 30,000 cubic yards have been put, by this means, into an embankment, only 24 chains in length.

Smiths' and foundry work is moderately good, but the class being so small and the material being English, almost all supplies of manufactured iron have had to be procured from England. Plate-laying was of course entirely a new operation, yet a large quantity of excellent work has been turned out by native labour under close inspection.

Among the mechanical improvements and innovations made by railway construction, may be enumerated, the use of barrows, dobbin carts, waggons and waggon roads, lorries, both wooden and iron, water pumps, crabs, moulding tables for brickmaking, stationary-engine power for sawing, pumping, and working tunnel shafts, hammer drilling, bridge centering, pile driving, timber pickling, and various kinds of iron superstructure for bridges.

The average cost of the opened portions of the line has been from about £8,000 to £9,000 per mile.

The prices of the principal kinds of work, including all the usual contract stipulations, have ranged as follows:—

		£.	s.	d.		£.	s.	d.
Earthwork in embankment under a quarter of a mile lead	per cubic yard, from	0	0	6	to	0	0	7½
Cutting in earth, or moorum, ditto	,,	0	0	7½	,,	0	0	9
Ditto in rock ditto	,,	0	1	1	,,	0	2	6
Tunnel	,,	21	10	0	,,	33	0	0
Brickwork in arches	,,	0	15	0	,,	1	10	0
Coursed rubble masonry in ditto	,,	1	7	0	,,	1	16	0
Ashlar	cubic foot	0	1	7½	,,	0	3	0
Block in course	cubic yard	0	16	0	,,	1	15	0
Coursed rubble	,,	0	14	0	,,	1	4	0
Rubble	,,	0	9	0	,,	0	14	0
Woodwork (teak)	cubic foot	0	4	0	,,	0	6	0
Ballast	cubic yard	0	1	1½	,,	0	1	4½
Laying permanent road	lineal yard	0	2	0	,,	0	2	10½
Post and rail fence	,,	0	1	6	,,	0	2	0
Dry rubble wall	,,	0	2	6	,,	0	4	0

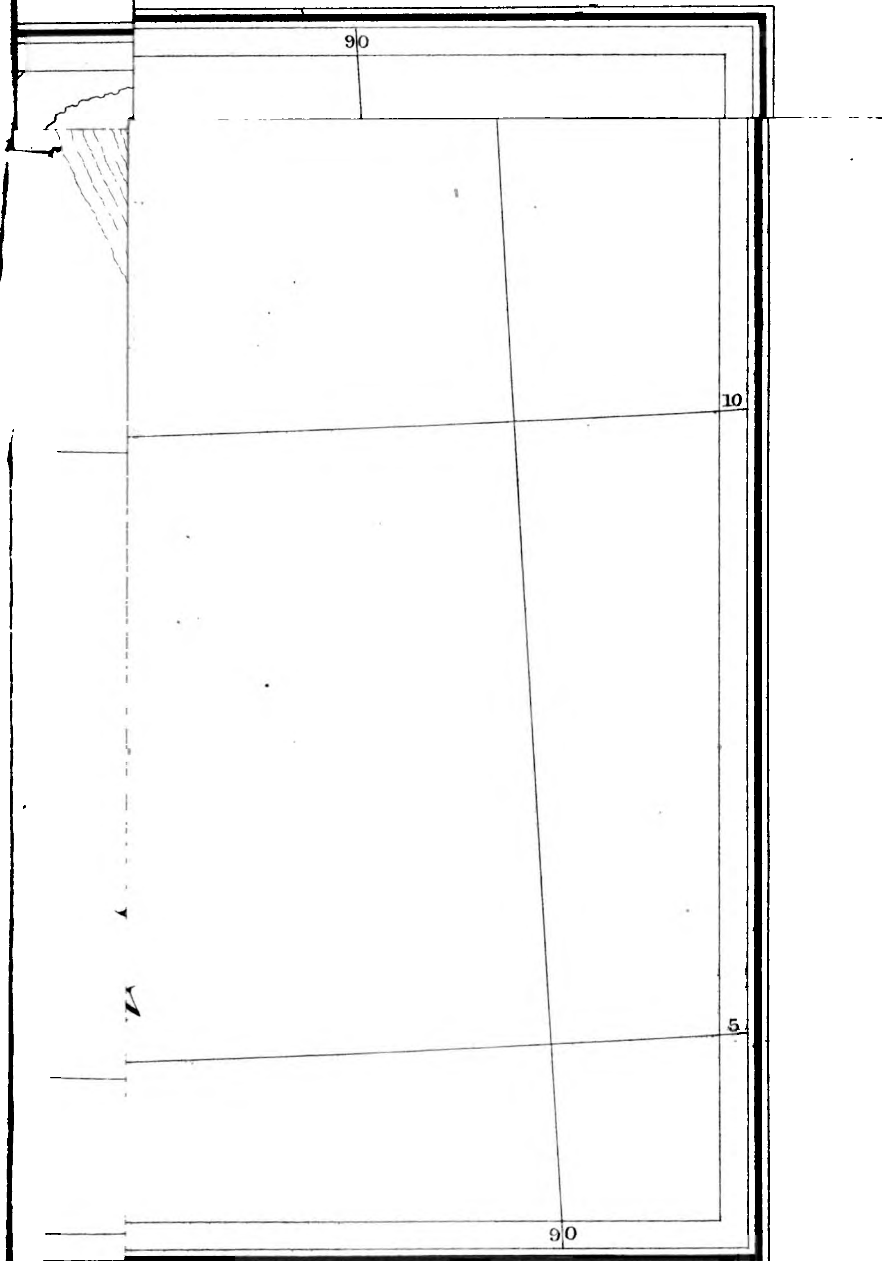
This does not include the Ghaut Inclines, which are exceptional.

Railway enterprise has already produced important effects in Western India. It has earned, at a remarkably low tariff, more than the guaranteed dividend. The working expenses have been moderate, notwithstanding the dearness of imported fuel and European superintendence. It has afforded the advantages of the best mode of conveyance, to immense numbers of the poorest and lowest orders of the people. It has generated for itself new sources of traffic. It has achieved its success in competition with water carriage, and when it was in only a fragmental state. Although constructed in what is, erroneously, called an expensive style, the traffic has already demanded the partial laying of a second line of rails. Within the Bombay Presidency, it has given simultaneous employment to one hundred thousand natives. It has raised the wages and increased the effectiveness of native labour, by encouragement, improvement, and organisation. It has, necessarily, employed thousands of the carriers of the country. It has greatly increased the tonnage of the port. It is expending about £1,000,000 sterling per annum in the districts, among small traders, ryots, artisans, and village labourers. It has opened quarries and brickfields, has impelled trade into unwonted activity, and has drawn largely upon the resources of the country. It has introduced into India, hundreds of new patents and ingenious contrivances. It has lessened the expenditure of the State, by its cheap conveyance of mails and troops, and has augmented its income by large payments of tolls and duties.

To conclude, in the words of the Right Hon. James Wilson, in his late financial statement to the Council of India:—"I never saw greater signs of industrial vitality, all full of promise for the future prosperity of India. Those who have seen the rush of third-class passengers on a holiday in Belgium, can, from that, form the best idea of the use made of these railways. What we require is their completion at any cost, but quickly, and we shall see a result for which the most sanguine are not prepared."

The Paper is illustrated by several diagrams, from which Plate 7 has been compiled.

[Mr. George Berkley,



Kell Bros. Lith.rs Castle St. Holborn.

Mr. George Berkley, as the representative of the Author of the Paper, and as officially connected with the Great Indian Peninsula Railway Company, stated, that when he received the Paper from his Brother, now in India, it was accompanied with a request, that he would make any additions to it which he thought desirable. He believed he had exercised a wise discretion in submitting the Paper to the Institution, almost exactly as it was written by the Author; because it was complete in itself, and the Author, who had borne the brunt of the work in India, and upon whom the chief responsibility rested, should have, therefore, all the credit that attached to it. He had also been requested to illustrate the Paper, and he had done so by maps and tables, to which he would briefly allude, because, in addition to the Paper itself, which dealt chiefly with the works of the Great Indian Peninsula Railway, they referred, generally, to the system of railways which had been sanctioned by Government, and were under construction in India.

In the absence of Mr. Rendel, the Consulting Engineer of the East Indian Railway, he would give some particulars respecting that line, which extended from Calcutta to Delhi, with a long branch to Jubbulpore and three shorter branches to Raneegunge, the Barrackur river, and the Singarrow valley. The length of the line was 1,338 miles, and the length already opened for public traffic, 295 miles. On the East Indian Railway, although it was of so great a length, there was only one tunnel, 300 yards in length. The principal works consisted of viaducts. In the crossings of the Rivers Soane and Jumna and two others, the railway was carried at the top, with a roadway underneath for the ordinary traffic, in a somewhat similar way to the High-Level Bridge at Newcastle. These four bridges were constructed upon the wrought-iron lattice principle, and were extensive works. The bridge over the Soane consisted of twenty-eight openings, with a span of 150 feet; that over the Jumna of fifteen openings, of which the span was 205 feet. The bridge over the Adjai consisted of thirty-two openings, with a span of 50 feet; that over the Keeul, of nine openings, with a span of 150 feet; and that over the Tonse, of seven openings, with a span of 150 feet. In the prosecution of this railway, a coal field of considerable extent had already been tapped; the coal was used as fuel for the locomotive engines, and was carried in large quantities along the line. This was the first instance, in India, of the development by railways of that most valuable mineral, coal.

The estimated capital of the East Indian Railway was £19,000,000, rather more than £14,000 per mile. The cost of the finished portions of the line had been £12,500 per mile: there was, therefore, every probability, that the whole of the works

would be carried out within the estimates. The cost of these railway works had been largely increased by the recent mutiny, to the extent, it was estimated, of not less than £3,000,000. The following were the rates of wages per day, both before and after the mutiny:—foremen carpenters, from 9*d.* to 13½*d.*; ordinary carpenters, from 6*d.* to 7*d.*; blacksmiths' foremen, from 9*d.* to 13½*d.*; ordinary blacksmiths, from 5*d.* to 7*d.*; masons, from 4*d.* to 7½*d.*; coolies, from 1½*d.* to 2½*d.* He hoped on a future occasion, that the Institution would be favoured with a Paper descriptive of the works on the East Indian Railway.

The Author had given so full a description of the Great Indian Peninsula Railway, that it was unnecessary to do more than call attention to the following points: that the total length of the line was 1,266 miles, of which 246 were already opened; that the estimated cost was about £10,000 per mile; and that the portion already opened, had been constructed at an average cost of £8,758 per mile, so that there was every reason to believe, that the estimate would not be exceeded.

The materials sent from this country for the use of Indian railways, were similar to those employed on English lines. The engines had cylinders 15 inches in diameter, with a stroke of 22 inches, and four coupled wheels, each 5 feet 6 inches in diameter. Those intended for use upon the inclines were tank engines, having cylinders 15 inches in diameter, with a stroke of 2 feet, and four wheels, each 4 feet in diameter, with skid breaks which did not pass under the wheels, but were pressed upon the rails between the wheels, on each side of the engine. The specimens of permanent way materials which he had brought for the inspection of the Meeting, showed, that they were the best that this country could, at any reasonable price, afford. It was of great importance, where the freight was so heavy an item, and the question of renewal was also so serious, to have the best quality of materials.

It might be interesting to learn how largely wages had increased in Bombay. Comparing a report from an inspector in that Presidency, of the rates of wages in 1853, with those in 1859, given in the Paper, he found, that the increase of wages in Bombay had been larger than in Bengal, and he believed, than in the other Presidency also. The wages of masons had risen, from 9*d.* to 1*s.* 6*d.*; of carpenters, from 9*d.* to 1*s.* 6*d.*; of miners from 7½*d.* to 9*d.*; and of bigaries, or labourers, from 4½*d.* to 6*d.* It must not be inferred, that the cost of the works had risen in the same proportion; because, as the workmen became accustomed to the use of mechanical appliances, they earned more money than before, they were better fed and protected, and their work, consequently, became more valuable. He considered a

material element of prosperity to have arisen from the introduction of these large works into India; for it was an undoubted gain to a country, when the amount of labour an individual workman could perform, was largely increased, or doubled. With reference to the salaries and wages paid to persons who went out to India from this country, he might state, that there were three classes of Resident Engineers. The first class,—he did not mean those who had the chief superintendence, but those to whom districts were assigned,—received £780 per annum: the second class, £660: and the third class, £540. The salary of the Locomotive Superintendent, was £1,080. The foremen of the several mechanical departments were paid various rates, from £20 to £35 a month. Engine fitters, engine drivers, coppersmiths, general smiths and coachmakers, received £16, £18, and £20 per month, respectively, for three years: permanent-way inspectors had £14 per month, with no addition during the three-years' engagement. He did not know whether that circumstance influenced the supply, but this was the most difficult class to procure. He believed, that it was desirable, in order to induce persons to go out from this country, that they should have the stimulus of an annual increase in their salary; unless they had that prospect before them, they were not tempted to leave England. It was satisfactory to be able to state, that with but few exceptions, the whole of the engineering staff of the Great Indian Peninsula Company had saved money. Living was very cheap in India. One engine driver who went out as a fireman, at £9 per month, and who, six months afterwards, was raised to the position of engine driver, at £16 per month, in addition to liberal allowances under special circumstances, had saved, during the sixteen months he had been engaged, £100. This driver stated, that he had everything necessary for a working man, and lived luxuriously for £3 per month; his definition of luxury being curries and beer. He hoped these statements would induce able men to go out to India, to aid in the development of the valuable system of railways in that country.

The Madras Railway started from Madras to join the Great Indian Peninsula at the River Kristna, thereby connecting Bombay and Madras: it also connected Madras and Beypore. It was unnecessary to enter into any particulars respecting it, as he saw present, not only the Consulting Engineer, but also the late Chief Resident Engineer of the line, who had done himself great credit in the management of that undertaking. The Madras Railway as well as the Bombay and Baroda Railway, and the Great Southern of India, were in course of construction, without the intervention of contractors. It would be interesting to hear the reasons, which had induced the able and experienced Engineers of

those railways to adopt that course. From the Paper it appeared, that very good practical results had been derived from the introduction of the contract system on the Great Indian Peninsula Railway. He need not dwell for more than a moment, upon the importance and value of subdivision of labour, as practised in the manufactures of this country, where the principle was universally adopted, in the most minute, as well as in the greatest works. One of the most striking examples of this, was afforded by the introduction of the contract system in railways : the Engineers designed, estimated, and superintended the works, whilst men whose practical knowledge fitted them for the task, undertook the organisation of labour, the purchase of materials, and the actual execution of the works. That the system had been productive of great good in this country, was not doubted ; it would, therefore, be interesting to learn why it had not been applied in those parts of India, where the railways he had named, were in course of construction.

The Scinde Railway, although it consisted of three companies, —the Scinde Railway Company, the Indus Steam Company, and the Punjab Railway Company,—was, in point of fact, but one system. There was also a line under survey, from Lahore to Delhi which was not indicated on the map, (Plate 7), as the route was not yet determined. He hoped, that in the course of the discussion, some information would be elicited, with regard to the difficulties that had been experienced in the navigation of the Indus, and the manner in which it was proposed to surmount them.

It would also be highly interesting to have some information respecting the bridges on the Bombay and Baroda Line, which were made entirely of iron, somewhat similar to the celebrated bridge in Wales, and consisted of spans of 60 feet, which he understood were duplicates.

The Eastern Railway of Bengal, and the Calcutta and South Eastern Railway, were also works of interest. In connection with the latter, he believed dry docks were to be constructed.

The average cost of railways in England, up to the end of 1858, was about £38,700 per mile; in Scotland, about £27,500 per mile; and in Ireland, about £15,000 per mile; making an average of £34,243 per mile. That amount applied to 9,323 miles, of which about 3,100 miles were single lines. On the Indian railways it was proposed, in the first instance, to lay down single lines of permanent way, except on such portions as those between Bombay and Callian, and the two Ghaut Inclines, where double lines would be laid. Their estimated cost was from £6,000 to £14,000 per mile, giving an average of £11,000 per mile, and there was every reason to hope, that

this would be found sufficient for their construction, as whilst the East Indian Railway was estimated at £14,480 per mile, the part now constructed had only cost between £12,000 and £13,000 per mile; of the Great Indian Peninsula Railway, which was estimated at £10,000 per mile, the parts completed had cost less than £9,000 per mile; and of the Madras Railway, which was estimated at about £8,500 per mile, the part constructed had only cost about £7,000 per mile. But it would be unjust not to mention, that in India there were no charges for Parliamentary expenses and land, whilst in England, there was high authority for estimating them at 25 per cent. of the total cost of railways. There were also many other important matters, such as the permanent and extensive character of the station accommodation on English railways, which should be taken into consideration, if it were desired to institute any comparison between the two systems of railway.

It appeared from the Paper, that as many as one hundred thousand men had been employed upon the Great Indian Peninsula Railway, the average number being about forty thousand. Looking at the length of that line and comparing it with the whole system, the conclusion would be arrived at, that within the last four, or five years, there had been a minimum of one hundred thousand, and a maximum of three hundred thousand, or four hundred thousand persons employed upon railway works in India. Within the same period of time, about £14,000,000 had been expended in labour, the effect of which had been to raise the rate of wages, and to increase the capacity of the men employed. Experience proved, that no native prejudices, or other circumstances would interfere to prevent railways from being used for the benefit of India, and that they would be extensively employed for the conveyance of goods, as the best and cheapest modes of transit.

But the beneficial effects of the introduction of railways into India, had not been limited to the people and trade of that country. It was true, that England had found the greater part of the capital for these undertakings, but her manufactures at home had been very largely benefited by them. Within the last four, or five years, 700,000 tons of railway material had been sent from this country to India, independently of contractors' materials. Those 700,000 tons of material had cost about £10,500,000. In 1859, 208,000 tons, chiefly of iron, were shipped for India, which was equal to about one-sixth of the whole exports of the country, during the previous year.

He had spoken of the number of persons temporarily employed in the construction of these railways; he would now notice the number that would, probably, be permanently employed, and here

the comparison with England was one of some interest. In England, in 1858, there were employed upon 9,323 miles of railway, 109,328 persons or an average of 11·7 men per mile. In India, in 1859, there were 590 Englishmen and 7,855 natives employed on 586 miles of line, giving 1 Englishman and 13·5 natives, or 14·5 men per mile. When all the lines at present sanctioned were completed, viz., 4,821 miles, there would be about 70,000 people permanently employed upon the Indian railways.

The question of fares for passenger traffic was one of some interest: upon this subject he would confine himself to the Bombay Presidency. On the Great Indian Peninsula Railway, the fares were, per mile, for the first class, 2·25*d.*, or $2\frac{1}{4}$*d.*; for the second class, ·75*d.*, or $\frac{3}{4}$*d.*; and for the third class, ·37*d.*, or $\frac{3}{8}$*d.* per mile. In England, Scotland, and Ireland, the fares varied but little: in England they were respectively, for the three classes, 2·16*d.*, 1·48*d.*, and ·88*d.*; in Scotland, 1·70*d.*, 1·51*d.*, and ·88*d.*; in Ireland, 1·82*d.*, 1·36*d.* and ·80*d.* The speed in the Bombay Presidency was from sixteen miles to twenty miles per hour, including stoppages, while in England it was from twenty miles to the express speed of thirty-eight miles per hour. The mean number of miles open in Bombay in the year 1859, was 195, and in the United Kingdom in 1858, it was 9,323 miles. The total number of passengers in Bombay was 1,161,501; and in the United Kingdom, 139,193,699. The average distance travelled by each passenger in Bombay, was 32·4 miles, while in England, the average distance travelled was only 12·7 miles. The number of passengers, per mile of railway, was larger in Bombay than in Great Britain and Ireland; in the former, it was 192,974, and in the latter, 189,611. The total number of passengers by railways in India in 1859, was 2,822,382, 93 per cent. being third-class passengers, probably consisting chiefly of the lowest classes of the native population. On the Great Indian Peninsula Railway, the receipts for passengers amounted to £453 per mile, and for goods, £464 per mile; in Great Britain and Ireland, £1,112 per mile for passengers, and £1,458 per mile for goods. Notwithstanding the very high price of fuel in Bombay, coals being £3. 3*s.* per ton, the working expenses did not exceed those in England. The dividend earned by the Bombay Line was £5. 14*s.* per cent., and by the East Indian Line, more than 7 per cent.; in England, the average dividend was about 4 per cent.

He could not leave this part of the subject without remarking, that the greatest credit was due to those gentlemen who had gone to India, and had devoted their best energies to the development of the traffic and to working it in the cheapest and best way; who had set aside all prejudices and personal feelings; and who, in all

cases, had laboured for the good of Her Majesty's subjects in her Indian dominions.

With regard to the future prospects of these enterprises, he looked again to English experience. The Author of the Paper had remarked, that the necessity for railways in India, was not to be measured by the present extent of the commerce of that country. England afforded a striking illustration of the truth of this statement; for from the time that railways were first introduced and developed in this country, say from 1830 to 1858, the population had increased about 42 per cent., whilst the exports of the principal articles of manufacture had increased from about 200 to 1,000 per cent. The exports of cotton twist, &c., had increased during this period, from about 65,000,000 lbs. to 200,000,000 lbs.; of calicoes, &c., from about 245,000,000 yards to 1,517,000,000 yards; and of iron and hardwares, from about 131,000 tons to 1,349,000 tons. He did not maintain, that these results were entirely owing to the construction of railways, but he ventured to assert, that they would never have been obtained without railways, and they led him to hope for similar results from the development of the railway system in India, in opening out the vast resources of that country.

He had now been connected with Indian Railways for ten years, and he was desirous of communicating all the information he could, in the hope, that the attention of Engineers would be directed towards extending and perfecting the railway system in India, and thus promoting the development of the resources and the civilisation of the large native population of that country.

In answer to a remark from the President,—that without a statement of the earnings per train mile in India, there could be no basis for the comparison of the working expenses there and in England,—Mr. Berkley added, that he had not intended to institute a comparison between the working expenses; as although the cost of fuel was large in India, the railways were working with new plant; and although there was some expensive labour, there was also a great deal of cheap labour. He did not consider, that the circumstances admitted of a direct comparison.

Mr. Bruce stated the reasons which induced him, in the construction of the Madras Railway, to associate, in his own person, the apparently double functions of Engineer and Contractor, a course so different from that generally adopted in this country. He had never ignored the benefits to be derived from the division of labour, nor did he condemn the employment of contractors; but no general rule, could, or ought to be laid down upon the subject; under certain circumstances, and indeed most frequently, the works must, of necessity, be undertaken by contractors. But in Madras there were no large contractors available; it became, therefore, a

question, whether he should begin the works at once, within two months of landing, or whether he should allow a year, or two years, to be consumed in correspondence with the administrative body in England. If he had gone direct from England to Madras, he should not have deviated from the ordinary rule; but having previously had, in Bengal, some experience of the ease with which natives might be organised for railway work, and seeing that contractors in India were, at that time, in no better position than the Engineers, he did not hesitate to begin the works of the Madras Railway on his own responsibility. He did not, for a moment, call in question the propriety of others adopting a different plan; but he had no doubt, that under the circumstances in which he was placed, he had pursued the best course. Another fact must also be taken into consideration; in carrying out works in India, very little plant was required; it might almost be said, that the less there was, the better. He began, at Madras, without any materials from England, and before it was possible to import any, the natives had found their own tools and earth baskets. As there were no long 'leads' from cuttings into embankments, there was no necessity for temporary rails; all that was required were good labourers, to whom a certain length of work was let. The first party engaged, undertook six miles of earthwork, the first out of Madras, at a price rather less than one penny per cubic yard. The other parts of the line were also let, wherever it was possible, to sub-contractors who were paid weekly; and he never had any difficulty, within a reasonable distance of Madras, in getting people to take these contracts. In so doing, he had only followed, after all, the old method, the plan on which Smeaton built the Edystone Lighthouse, and on which Stephenson constructed the Stockton and Darlington, and the Liverpool and Manchester Railways. At the same time, he perfectly admitted, that the intervention of contractors was desirable, whenever it was possible to get responsible men to undertake the work at fair prices. By that system, the Engineer relieved himself of a great amount of responsibility and continued anxiety, which sometimes led to fatal consequences.

He added his testimony to what, he was sure, was the sense of the Meeting, that this Paper was a most valuable one, as the Author, in the popular description he had given of the Bombay Railway, had also sketched the general features of all the Indian railways. With most of the points mentioned, he cordially agreed, and with regard to those from which he differed, he acknowledged the fairness and ability with which the Author had stated his case. There was one topic alluded to, which called for remark; it was stated, that the substantial system had been adopted in contradistinction to what was called, the American system. It always appeared to him, that there was a popular

delusion in the minds of the public upon that subject. Engineers were repeatedly asked, why the American system was not adopted in the Indian railways, and why so much money was spent upon them. Now the fact was, that what had been incorrectly called the American system, had, in reality, been followed, if by that term was meant the practice of taking advantage of the cheapest and best materials to be found upon the spot. It would be folly to maintain, that because timber was used in America, where it was cheap, it ought also to be employed in India, where it was dear, but where there was abundance of good stone, and bricks.

The prices of labour in Bombay were much higher than in Madras. In the latter Presidency, the ordinary prices per day were; —coolies, 3*d.*; women and boys to assist in carrying the earth, 1½*d.*; carpenters, from 9*d.* to 10½*d.*; bricklayers, 7½*d.* to 10½*d.* These rates were about the same as those now paid upon the Great Southern of India Line. The ordinary price of earthwork was 1½*d.* to 2*d.* per cubic yard; and of masonry, 7*s.* 6*d.* to 10*s.* per cubic yard; and works, which were usually let to contractors, such as making embankments, building bridges, laying the permanent way, and ballasting the road, cost about £1,500 per mile, exclusive, of course, of materials and stations.

He could confirm, in every respect, the observations in the Paper, that the railway works of India had materially contributed to the improvement of the people. Their whole appearance was changed for the better; there was plenty of money amongst them, and they had now the means of living well. The coolies were daily increasing in size and strength, as also in mechanical ability. He ought to have mentioned, when speaking of the system he had adopted in Madras, that he never made a written contract. Every arrangement took place by word of mouth, and no money was ever advanced before it was earned. The ordinary practice in India was to pay in advance, one-half, or more, of the value of the article ordered, which was proof of the absence of proper confidence between the employers and employed. He had been warned, by men long acquainted with India, that the system he proposed to adopt, would fail. He found, however, that when the natives were once impressed with the honesty of those who employed them, and of their readiness to fulfil all their engagements, there was not the least difficulty in procuring labour. But his reason for not entering into written contracts, was the possibility, from the well-known mania of the natives for litigation, of his being continually involved in lawsuits.

Allusion had been made to the advantages of the guarantee system. It had been his fate to have been occasionally placed in a rather prominent position of hostility to that system: he was

glad, therefore, to take this opportunity of stating, from the experience of some years past, that the manner in which the Government supervision of the works had been exercised, was all that could be desired. The course pursued by Captain Johnson in connection with the lines in Madras, had been in the highest degree satisfactory to those concerned; and he was sure, that all those who had been connected with Indian railways, would not do justice to their own feelings, if they failed to express, on every occasion, their admiration of the extraordinary ability and the high gentlemanly bearing which had always been manifested by Sir James Melville, in the management of that department of the Indian Government in this country.

Mr. Longridge said, the line in India with which he was connected was comparatively so insignificant, that it offered little interest in an engineering point of view. It possessed, however, great commercial interest, the chief object of that line being to relieve the over-crowded and somewhat dangerous port of Calcutta, by the creation of a subsidiary port on the Mutla. The trade of the province of Bengal had increased so rapidly, and the dangers of the navigation of the Hooghly were so much enhanced, partly, perhaps, owing to the increased size of the vessels, that the necessity for a new port had become evident. When he went to India in 1856, to survey this line,—the Calcutta and South Eastern, from Calcutta to the River Mutla,—he was struck with the capabilities which that river, or rather arm of the sea, presented for the formation of a new port. At low water there was, throughout, a minimum depth of 24 feet, whereas in the Hooghly there were many shoals, with not more than 15 feet of water over them. Those shoals were at such distances from each other, that it was impossible to get over more than one, or two of them, in a tide. Unlike the Hooghly, the Mutla was free from bores and dangerous eddies; it was kept open by the tidal flow, which did not exceed, at any time, four miles per hour, through the channels of the Sunderbunds; and as no fresh water entered it, there had been little, or no change in the depth of water; there was, moreover, no bar. Ships of all burthens would be able to come alongside the intended wharves, and discharge their cargoes, at once, into the railway trucks. The traffic from Calcutta, for about three months in the year, was, at present, brought down the Nuddea Rivers, running nearly due north from Calcutta, but except during the rainy season, those rivers were not navigable; at other times, the whole of the traffic, which, in 1856, amounted to 1,667,000 tons, had, therefore, to be brought round, through the most intricate navigation of the Sunderbunds, to the head of the River Mutla, thence it passed up the Biddiadhurree River and then again through the Circular Canal to Calcutta. The scenes which took place upon that canal, must be seen to be believed.

At high water it was, frequently, so crowded with vessels, that when the tide fell, they crushed up together, and the weakest went to the bottom. He had himself occupied from four hours to five hours in getting two miles, in a dingy. The port on the Mutla was the only one in India capable of receiving the 'Great Eastern;' it could be moored alongside the wharf at the railway station to discharge both passengers and cargo direct for Calcutta, which was at a distance of 28½ miles. There was no necessity for wet docks; graving docks only would, therefore, be constructed by the Company, who also intended to erect wharf walls, with hydraulic cranes for discharging cargo.

The system of executing the works without the intervention of contractors had been adopted, because the line was short, and the works were, generally, of such a nature as not to require any plant. There were only two bridges of any importance; one with a span of 170 feet, the other of 125 feet. The foundations were not difficult, and he proposed that the bridges should be formed of iron girders resting on brick abutments. It must not be inferred, that he was systematically opposed to the employment of contractors; on the contrary, he thought it would have been almost impossible to have carried out many large works, without their intervention.

Mr. HAWKSHAW, V.P., as the Consulting Engineer of the Madras Railway Company, had seen no occasion to differ from the mode adopted, of carrying on the works by small sub-contracts, and dispensing with the intervention of large contractors. It was unwise to enunciate general rules, as to whether railway works should be executed by large, or small contracts, or be conducted under the immediate control of the Engineer; everything must depend upon the circumstances of each individual case. In England there existed the means of obtaining fair competition for contracts, from a valuable class of men, educated to the business and possessing a thorough knowledge of the manner in which the work ought to be executed; and he believed, that most Engineers had arrived at the conclusion, that in England, this was the best mode of conducting public works. But it was not always possible to adopt the same plan in a foreign country. There was great difficulty in obtaining proper competition for contracts in a country like India. He had under consideration, at the present time, the best mode of carrying out railway works in some of the Colonies, yet with all his experience, he found it an embarrassing question. There were so many difficulties in the way of obtaining offers from a competent number of persons, to perform works of the cost of which the Engineer himself could have no very precise knowledge, that the contractors were tempted to add a considerable sum, to provide against the contingencies which might arise. He had also the honour to be the Consulting Engineer of

the Eastern Bengal Railway, which was carried on upon the contract system; thus having railways in India under construction on both systems, he should, in a few years, be able to give a sounder opinion as to their relative superiority. But with his present experience, he approved the course which had been pursued, in commencing the Madras railway, and judging merely by the cost of that line, experience had pronounced in its favour.

The question had been mooted, whether Indian railways ought to be constructed substantially, or on the principle which was adopted, some years ago, in America. It was his decided opinion, that as a rule, temporary works were proper for temporary purposes only; but that, occasionally, from want of funds, it might become necessary to adopt temporary structures for permanent objects. In an old country like India, where there was an immense population, a large amount of traffic, and the prospect of a fair return upon the outlay, the best materials only should be employed. It was as bad policy in India, as it was in England, to use inferior sleepers, or bad rails; because those portions of a railway wore out sooner than the rest. The same remark applied to bridges and other similar works; yet, in some cases, where the timber could be depended upon to last fourteen, or fifteen years, it might, with propriety, be employed for viaducts, provided that by using timber, the structure could be erected for about one-half the cost of iron, or stone, which would permit of its being rebuilt at the expiration of that time; but if the timber was liable to decay in five, or six years, that course would be inapplicable.

He thought that, at present, there were no fair grounds for comparison between the cost of railways in India and in England. His own experience proved, that the cost of many of the English railways had been nearly doubled, during the last fifteen years. No useful conclusions could, therefore, be drawn, from a comparison between the cost of a new line of railway and that of an old one. On the lines with which he was connected, almost all the stations had quadrupled in size and cost, during the period they had been under his charge. It would be the same, hereafter, in India; the rolling stock also would become more extensive as the traffic increased; and thus the ultimate cost, per mile, would be proportionately augmented. It must not be forgotten, when instituting comparisons of this kind, that there was not a single old railway that had not cost much more per mile, than when it was first opened.

He could not refrain, in conclusion, from expressing the great pleasure which this Paper had afforded him. It was a clear and lucid statement of what had taken place under the Author's own observation, and he felt, that the Institution was much indebted to him, for having favoured them with this communication.

Mr. BIDDER,—President,—said, that the great experience of the Author in Indian railway work, had enabled him to present to the Institution one of the most instructive Papers that had ever been laid before it. For his own part, he regarded it as a perfect model for such communications; he had never listened to a Paper with more pleasure and interest, or to one from which he had derived more information.

It was a subject for congratulation, that the results of the non-contract system had been so satisfactory on the Madras Line. Those who invested their money in Indian railways merely looked for interest on their capital, and although great supervision had been exercised over the expenditure by the Government, there was no personal interest to insure economy. Contractors might be said to be both bold and timid; bold, when the work was fairly understood, but timid, when there were contingencies in the background. In introducing a new class of labour into a new country, it was necessary, that the Engineer should pioneer the way, so as to ascertain the elements on which contractors might, subsequently, found their estimates; fair competition might then be relied on, and the contract system could be introduced with advantage. The remarks which had been made relative to the increased cost of railways in this country, had demonstrated, that no useful result could be drawn from a comparison of the cost of lines in England and in India. But there was one point of comparison which led to inferences of a useful character, that of the fares, and the average distance travelled by each passenger. The third-class fares in India seemed to be only about one-half as much as in England, whilst the average distances travelled by each passenger were, respectively, 32 miles and 12 miles. If the distance each passenger was conveyed in England could be increased, either larger dividends would be realised, or lower fares could be charged. It was well known, that the most intricate complications had arisen, from the contests of railway companies with regard to long fares; whereas it appeared to him, that the real prosperity of a railway was more dependent upon its local traffic, and that, in general, railway companies should endeavour to facilitate the construction of lines in the districts they traversed, so as to lead, ultimately, to an increase in the accommodation of the immediate population and in the conveyance of traffic.

Another subject had been incidentally alluded to, to which he more particularly referred, in the hope that Mr. Longridge would be prevailed upon to present a Paper to the Institution, enbodying the results of his experience as to the local circumstances connected with the navigation of the Hooghly and the Mutla. The Hooghly received a very large amount of inland water, and

was uncertain and changing in its depth, whilst the Mutla was kept open by the tidal water only, and preserved a uniform and invariable depth. There was no subject of greater national importance than that which concerned the régime of navigable rivers, and the effects of scour and tidal waters upon their channels; and a discussion upon that subject, independent of technical points, could not fail to be interesting and useful to the profession.

May 15, 1860.

GEORGE PARKER BIDDER, President, in the Chair.

The discussion upon the Paper, No. 1,025, "On Indian Railways," &c., by Mr. J. J. Berkley, occupied the whole evening, to the exclusion of every other subject.

May 22, 1860.

GEORGE PARKER BIDDER, President, in the Chair.

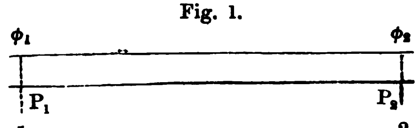
The following Candidates were balloted for and duly elected:—GEORGE HIGGIN, as a Member; JOHN GLADSTONE DAVENPORT, CHARLES JAMES FREAKE, SYDNEY LAWRENCE, and JOSEPH LEE THOMAS, as Associates.

No. 1,027.—"On a Method of computing the Strains and Deflections of Continuous Beams, under various Conditions of Load."[1] By JOHN MORTIMER HEPPEL, M. Inst. C.E.

1. THE method which forms the subject of this Paper is, in its main features, identical with that given in Moseley's "Mechanical Principles of Engineering and Architecture," and so successfully followed, in the deduction of practical results, by Mr. Edwin Clark, (M. Inst. C.E.,) and others. In one, or two points, however, the Author believes it to be new; and as some of the formulæ arrived at, appear to be of more general applicability, and of easier adaptation to the purposes of numerical computation than any he has yet seen, he is induced to offer to the notice of others what he has found useful.

2. The chief points in which the following method of investigation differs from others are, that in estimating the action of forces, more aid is derived from the theory of couples, and that in considering the pressures on the bearing points, the two parts of each such pressure, arising, respectively, from the portions of the beam on either side of it, are always kept separate and distinct. Much advantage will result from this separation, by the aid of which, chiefly, all the conditions of a continuous beam can be treated, with little greater labour, or complexity of calculation, than if it were a succession of independent beams.

Fig. 1.

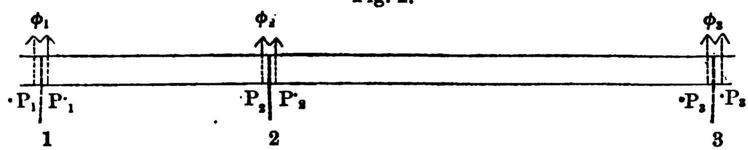


3. Let 1.2 (Fig. 1), represent an opening, or span, of a continuous beam, and call the elastic forces in action at the sections over the bearings 1 & 2, φ_1 & φ_2, the length l, and the load per unit of length μ. It is evident, that since all the forces in action on this

[1] This Paper, being of a purely mathematical character, was read in abstract.

part of the beam are in equilibrium, the sum of the two upward pressures P_1 & P_2 must be equal to the weight. It is true, that if the strain over either of the bearings, as ϕ_1, is produced by the action of an adjacent portion of the beam, which also carries a load, an additional pressure due to such adjacent load will be brought to bear on the support 1. In estimating the total pressure on this support, it would be necessary to take it into account, but its amount is deducible, exclusively, from the mechanical conditions of the adjacent span, from which it alone arises, and whether great, or small, it in no way affects the amount of P_1, which continues, as before, to be the vertical force arising from, and in equilibrium with, the other forces in action in the span 1. 2.

Fig. 2.



4. To make this more clear, as it is a point of some importance to what follows, let Fig. 2 represent two adjacent spans of a beam, and represent by ${\cdot}P_1\,P^{\cdot}_1$, ${\cdot}P_2\,P^{\cdot}_2$, ${\cdot}P_3\,P^{\cdot}_3$, the vertical forces in action, at sections of the beam exceedingly near to each other, on either side of the points of support. It must be obvious, that whatever may be, in other respects, the mechanical conditions of the two spans, the sum of the vertical forces $P^{\cdot}_1$ & ${\cdot}P_2$ must be equal to the weight of the part of the beam lying between 1 & 2; and the sum of $P^{\cdot}_2$ & ${\cdot}P_3$ will, in like manner, be equal to the weight of 2.3; also, that ${\cdot}P_2$ and $P^{\cdot}_2$ together make up the whole pressure on the support 2.

Returning to Fig. 1, it will be evident, that the sum of the pressures $P^{\cdot}_1$ & ${\cdot}P_2$ can in no way be affected by the mechanical conditions of the adjacent spans. By affecting the amount of the strains ϕ_1 & ϕ_2, a change in the condition of the adjacent spans, or of either of them, may, indeed, become productive of a corresponding change in P_1 & P_2 individually, but their sum nevertheless remains constant throughout, and their individual changes are simple results of the changes in ϕ_1 & ϕ_2, and would be exactly the same, whether these latter had been brought about by the action of the adjacent spans, or in any other way.

5. Taking account of all the forces in action on the span 1.2, (Fig. 1), there will be found to be three different couples of forces in action, any one of which may, according to the special conditions of the case, tend to turn the span under consideration, in either direction; and in order to avoid ambiguity in the use of the positive, or negative sign, by which the direction must be indicated,

it will be necessary, in the first instance, to determine the rule to be followed.

In the case of couples which act on one portion of the beam only, there is no difficulty about the sign, which will be + when the tendency is to turn forwards, or in the direction of the hands of a clock, and − when the tendency is backwards, or in the opposite direction. With reference, however, to such couples as ϕ_1, ϕ_2, &c., which act both on the span under consideration and on one, or other of the adjacent ones, and whose action, if positive on the one, is negative on the other, and *vice versâ*, there may be some risk of confusion, unless the conditions determining the sign, and its precise meaning, are kept in view throughout.

Each such couple then, must be considered as having its own proper, or essential sign, according as its action is direct, or retrograde, considered with reference to the portion of the beam lying always towards the same side of it; and it will be found most convenient, that this should be the left side; that is to say, that a couple whose action is to turn the portion of beam lying to the left of it, forwards, or in the direction of the hands of a clock, should always have the proper sign +, and one whose action is the reverse, the proper sign −. This is only saying, in other words, that those in which the top is extended and the bottom compressed, are positive, and those in which the reverse obtains, are negative. This sign is, however, indeterminate, until, from the solution of an equation, or otherwise, the particular value of the moment of the couple becomes known. In the mean time, ϕ_1, ϕ_2, &c., represent quantities which may be positive, or negative, according to circumstances.

In bringing these quantities into equations, another circumstance must be considered; whether they are regarded with reference to their action on the part of the beam to the left, or on that to the right of them. In the first case, their action will always be accurately represented by their proper sign, whatever that may be; but in the second case, it will be the reverse. Both cases will, therefore, be provided for by writing the sign +, before all couples which are considered with reference to their action on the portion of the beam lying to their left, and the sign − before those considered with reference to the right. The proper signs of the values of the couples resulting from the solution of such equations, will always accurately indicate the direction of their action.

Bearing these things in mind, there are acting in the span 1.2, the couples ϕ_1 & ϕ_2, to the first of which must be prefixed the sign −, inasmuch as its action is considered with reference to a portion of the beam lying to its right, and to the second, the sign +, for the converse reason. Next, there is the couple whose components are the whole load acting through its centre of gravity,

and the equal and opposite force $P_1 + P_2$, acting through the centre of pressure of P_1 & P_2. The moment of this couple is easily shown to be $(P_1 - P_2)\frac{l}{2}$, and as it acts on the span 1.2 alone, and on no other portion of the beam, there is no ambiguity as to its direction, which is positive when P_1 is greater than P_2, and negative in the contrary case. Therefore, the positive sign may always be prefixed to the above expression, and the proper sign of the result, obtained by assigning any particular values to P_1 & P_2, will accurately indicate the corresponding direction of its action.

7. Now since these three couples are the only forces acting on the span 1. 2, they must mutually balance, and

then, $$-\varphi_1 + \varphi_2 + (P_1 - P_2)\frac{l}{2} = o;$$

also, $$\mu\, l - (P_1 + P_2) \quad = o.$$

Hence, $$P_1 = \frac{\mu\, l}{2} + \frac{\varphi_1 - \varphi_2}{l} \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

$$P_2 = \frac{\mu\, l}{2} + \frac{\varphi_2 - \varphi_1}{l} \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

in which φ_1 & φ_2 may be properly positive, or negative, in any particular case, according as their tendency is to turn the portion of the beam lying to the left of them forwards, or backwards.

P_1 & P_2, it will be observed, may also either of them become negative, indicating an upward, instead of a downward pressure on the bearing; but never both of them together, as their sum is always $\mu\, l$, whatever φ_1 & φ_2 may be.

8. Returning now to Fig. 2, call the lengths of the two contiguous spans l_{12} & l_{23} and the loads per unit of length μ_{12} & μ_{23}; also call the tangent of the inclination of the deflection curve over the bearing 2, T_2. Let the strain at any distance x from the point 2, in the span 2.3, be called φ.

Then, with reference to the portion of the beam between 2 and x,

$$-\varphi_2 + \varphi + P'_2\, x - \mu_{23}\frac{x^2}{2} = o.$$

Hence, by a well-known process, remembering that where y is the deflection at x, $\varphi = EI\,\frac{d^2 y}{d\, x^2}$; and that at the point 2, $\frac{d\, y}{d\, x} = T_2$,

$$EIT_2 = -\varphi_2\frac{l_{23}}{2} + P'_2\frac{l^2_{23}}{6} - \frac{\mu_{23}\, l^3_{23}}{24} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

Similarly, if the position of the beam be reversed, that is, turned right for left, and the conditions of the span from 2 to 1 be investigated in the same way,

$$-\mathrm{EIT}_2 = -\varphi_2 \frac{\underset{12}{l}}{2} + \cdot\mathrm{P}_2 \frac{\underset{12}{l^2}}{6} - \frac{\underset{12}{\mu}\,\underset{12}{l^3}}{24} \quad \ldots\ldots\ldots \quad (4)$$

But from 1 & 2,

$$\mathrm{P}\cdot_2 = \frac{\underset{23}{\mu}\,\underset{23}{l}}{2} + \frac{\varphi_2 - \varphi_3}{\underset{23}{l}} \quad \ldots\ldots\ldots \quad (5)$$

$$\cdot\mathrm{P}_2 = \frac{\underset{12}{\mu}\,\underset{12}{l}}{2} + \frac{\varphi_2 - \varphi_1}{\underset{12}{l}} \quad \ldots\ldots\ldots \quad (6)$$

Substituting these values in (3) & (4), adding them together, and clearing the fractions,

$$8\left(\underset{12}{l} + \underset{23}{l}\right)\varphi_2 + 4\,\underset{12}{l}\,\varphi_1 + 4\,\underset{23}{l}\,\varphi_3 = \underset{12}{\mu}\,\underset{12}{l^3} + \underset{23}{\mu}\,\underset{23}{l^3} \quad \ldots \quad (7)$$

In a continuous beam resting on any number of bearings, at equal, or unequal distances, and loaded in any way, so that the load on each span is uniform, it is evident, that an equation may be formed, such as the above, between any three consecutive φ's, as $\varphi_1\ \varphi_2\ \varphi_3$, $\varphi_2\ \varphi_3\ \varphi_4$, $\varphi_3\ \varphi_4\ \varphi_5$, &c.; and that the number of equations thus obtained, will always be two less than the number of bearing points. If then, the strains over any two of these be known, there are as many equations as unknown quantities, whence all may be determined. The most frequent case, and in fact, almost the only one occurring in practice, is where the first and last strains are known, and both are equal to nothing, being at the free ends of the beam.

The three equations, (5), (6), (7), will be found sufficient to determine the strains over the bearings and the pressures on the supports, in every case of a continuous beam of uniform section, and whose normal condition is straight, *i. e.*, which would, if relieved from all load, either extraneous, or arising from its own weight, just touch all the bearings.

9. If these conditions do not obtain, if the different spans are of different sections, and if the normal condition is not straight, then the expression requires the following modification, of which it is not necessary to give the demonstration at length, as it is arrived at by a method precisely analogous to that followed in determining the conditions of the Britannia Tube.[1] Put $\underset{12}{\mathrm{I}}$ for

[1] *Vide* "The Britannia and Conway Tubular Bridges, &c." By Edwin Clark. Page 774, *et seq.*

the moment of inertia of the section of the first span, and I_{23} for that of the second, and let $\dfrac{\mathrm{I}_{12}}{\mathrm{I}_{23}} = \iota_2$.

Moreover, if the different spans of the beam do not range in a straight line when all load is removed, the consequence is, that any two spans in which the condition obtains, as, for instance, 1.2, and 2.3, instead of having a common tangent to the inclination of their deflection curves at the point 2, will have two different tangents, which, call $\cdot\mathrm{T}_2$ & $\mathrm{T}\cdot_2$, and let $\cdot\mathrm{T}_2 - \mathrm{T}\cdot_2 = t_2$. $\mu_{23}\,\iota_2\, l^3$

The modified equation then becomes

$$8\left(l_{12} + \iota_2\, l_{23}\right)\varphi_2 + 4\,l_{12}\,\varphi_1 + 4\,\iota_2\, l_{23}\,\varphi_3 = 24\,\mathrm{EI}_{12}\,t_2 + \mu_{12}\, l^3_{12} + \cancel{\mu_{23}\, l^3_{23}} \qquad (8)$$

Expressions (5) & (6) require no modification, being absolutely true for all conditions.

The equations (8), (5), & (6) then, are sufficient for the determination of all the conditions of any continuous beam of equal, or unequal spans, with equal, or unequal loads, of equal, or unequal sections, and either normally straight, or in which the strains over the bearings are regulated, as in the Britannia tubes. The mode of employing them is, first to form a set of equations of the form of (8), between each three consecutive φ's, inserting the known numerical values of the other quantities. From them, all the φ's are determined. When these are found, insert their numerical values in equations of the form of (5) & (6), two for each span, from which all the P's are determined. It is plain, that these things being known, the whole of the conditions of each span, as to strain and deflection, become at once ascertainable, by the simplest processes, quite independent of the others; just as if it were a simple beam.

11. It may be useful, however, to enumerate the expressions to be employed, putting them in their most convenient form for the purpose of computation. The working out is not, however, given from a wish to avoid encumbering the Paper with a mere detail of well-known processes.

Taking then the span 1.2 as an example, the equation to its deflection curve

$$y = \frac{\mu_{12}}{24\,\mathrm{EI}} \times x \times \left(x - l_{12}\right) \times \left(x^2 + \left(x + l_{12}\right) \times \left(l_{12} - \frac{4\,\mathrm{P}\cdot_1}{\mu_{12}}\right) + \frac{12\,\varphi_1}{\mu_{12}}\right) \quad \ldots\ldots\ldots\ldots \quad (9)$$

which, if it is the deflection on the middle of the span that is required, becomes, by making $x = \frac{l_{12}}{2}$,

$$y = \frac{l^2_{12}}{384\ \mathrm{EI}} \times \left(24\ \mathrm{P}'_1\, l_{12} - 7\, \mu_{12}\, l^3_{12} - 48\, \varphi_1\right) \quad . \quad . \quad . \quad (10)$$

The position of the points where the deflection curve becomes horizontal may be obtained from the cubic equation,

$$\frac{\mu_{12}}{6} x^3 - \frac{\mathrm{P}'_1}{2} x^2 + \varphi_1\, x + \frac{4\ \mathrm{P}'_1 - \mu_{12}\, l_{12}}{24}\, l^2_{12} - \frac{\varphi_1\, l_{12}}{2} = o \quad . \quad (11)$$

the roots of which show the points where the tangent to the curve is horizontal. The corresponding signs of y & $\frac{d^2\, y}{d\ x^2}$ will show whether any particular one is a point of greatest elevation, or greatest depression. This will, however, generally be obvious from other circumstances. The points where the deflection curve cuts the horizontal line through the bearings, will be given by the quadratic equation,

$$x^2 + \left(l_{12} - \frac{4\ \mathrm{P}'_1}{\mu_{12}}\right) x + \left(l_{12} - \frac{4\ \mathrm{P}_1}{\mu_{12}}\right) l_{12} + \frac{12\ \varphi_1}{\mu_{12}} = o \quad . \quad (12)$$

whose roots show the positions of such points.

The point of maximum strain will be found from

$$x = \frac{\mathrm{P}'_1}{\mu_{12}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (13)$$

and for the strain at any distance x, from the point 1,

$$\varphi = \frac{\mu_{12}}{2} x^2 - \mathrm{P}'_1\, x + \varphi_1 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (14)$$

Lastly, for the position of the points of contrary flexure,

$$x = \frac{\mathrm{P}'_1 \pm \sqrt{\mathrm{P}'^2_1 - 2\ \varphi_1\ \mu_{12}}}{\mu_{12}} \quad . \quad . \quad . \quad . \quad . \quad . \quad (15)$$

Of these expressions, the only ones ordinarily requisite in practice are Nos. (5), (6), (7), (8), (10), (13), (14), & (15), all of which are tolerably well adapted to numerical computation.

12. It may be desirable to mention another modification of the general expression, for the case where, in addition to the dis-

tributed loads, there are concentrated loads $\underset{12}{W}$ $\underset{23}{W}$, &c., at the centres of the spans. It then becomes, as shown in the Appendix, (page 639,)

$$16\left(\underset{12}{l}+\underset{23}{l}\right)\phi_2+8\,\underset{12}{l}\,\phi_1+8\,\underset{23}{l}\,\phi_3=2\,\underset{12}{\mu}\,\underset{12}{l}^3+2\,\underset{23}{\mu}\,\underset{23}{l}^3$$
$$+3\,\underset{12}{W}\,\underset{12}{l}^2+3\,\underset{23}{W}\,\underset{23}{l}^2 \quad . \; . \; . \; . \; . \quad (16)$$

If, as in the case of a rail with supports at equal distances, the distributed load is altogether inconsiderable as compared with the concentrated load, this reduces to

$$4\,\phi_2+\phi_1+\phi_3=\tfrac{3}{8}\,l\left(\underset{12}{W}+\underset{23}{W}\right) \quad . \; . \; . \; . \quad (17)$$

or, if one span only, as 1.2, be loaded,

$$4\,\phi_2+\phi_1+\phi_3=\tfrac{3}{8}\,l\,\underset{12}{W} \quad . \; . \; . \; . \; . \; . \; . \; . \quad (18)$$

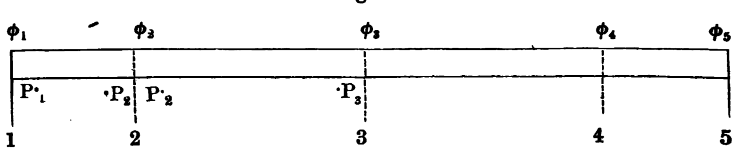
This is an exceedingly simple expression, by which the amount and direction of the strains on a rigidly-fixed rail, (supposing for a moment the possibility of its existence,) produced by the action of a load in the middle of any one of its spans, may be computed. If it is also desired to know the pressures, upward, or downward, on its supports, the expressions (5) & (6) must be thus modified :—

$$P^{\cdot}_1=\frac{\underset{12}{W}}{2}+\frac{\phi_1-\phi_2}{l} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \quad (19)$$

$${}^{\cdot}P_2=\frac{\underset{12}{W}}{2}+\frac{\phi_2-\phi_1}{l} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \quad (20)$$

13. To give an example of the application of the above to the purposes of computation, let the case of the Britannia tube, before referred to, be taken.

Fig. 3.



The following quantities are given :—

$\phi_1 = o$	$\underset{12}{l} = 230$	$\underset{23}{l} = 460$	$\underset{34}{l} = 460$
$\phi_2 = \phi_4$	$\underset{12}{\mu} = 2{\cdot}6$	$\underset{23}{\mu} = 3{\cdot}38$	$\underset{34}{\mu} = 3{\cdot}38$
	$\underset{12}{I} = 962$	$\underset{23}{I} = 1{,}584$	$\underset{34}{I} = 1{,}584$

$$\frac{\mathrm{I}_{12}}{\mathrm{I}_{23}} = \iota_2 = 0{\cdot}607324 \qquad \frac{\mathrm{I}_{23}}{\mathrm{I}_{34}} = \iota_3 = 1$$

$$\cdot\mathrm{T}_2 - \mathrm{T}\cdot_2 = t_2 = 0 \qquad \cdot\mathrm{T}_3 - \mathrm{T}\cdot_3 = t_3 = -0{\cdot}00407$$

E = 10,000 × 144, the dimensions being taken in feet.

Substituting these in the general equation (8), first taken for the spans 1.2 and 2.3, and next for the spans 2.3 and 3.4, and reducing, the following equations are obtained:—

$$\varphi_2 + 0{\cdot}2743\ \varphi_3 = 56{,}810$$
$$2\ \varphi_3 + \varphi_2 = 118{,}250$$

Whence $\varphi_2 = 47{,}030$, $\varphi_3 = 35{,}610$: (the values given by Mr. Clark, are 46,920 & 35,650). Substituting these values of φ_2 & φ_3 in equations (5) & (6), first for the span 1.2, and next for the span 2.3, there is obtained:—

$$\mathrm{P}_1 = 94{\cdot}5 \quad \cdot\mathrm{P}_2 = 503{\cdot}5$$
$$\mathrm{P}\cdot_2 = 802{\cdot}3 \quad \cdot\mathrm{P}_3 = 752{\cdot}7$$

P_2 (whole pressure on 2) $= \cdot\mathrm{P}_2 + \mathrm{P}\cdot_2 = 1{,}305{\cdot}8$

P_3 (whole pressure on 3) $= \cdot\mathrm{P}_3 + \mathrm{P}\cdot_3 = 1{,}505{\cdot}4$

(Mr. Clark gives $\mathrm{P}_1 = 96$ $\mathrm{P}_2 = 1{,}305$ $\mathrm{P}_3 = 1{,}504$).

It is unnecessary to pursue the comparison further; but the deflection from expression (10), and the points of contrary flexure from (15), will be found to compare equally well.

In order to show, that there is nothing formidable in the calculations necessary for obtaining numerical results from these formulæ, the entire calculation of the quantities involved in the above expression, is given in the Appendix, (page 641). The logarithms are only taken to four places of decimals, which gives the results with sufficient exactitude, and will, probably, account for the slight differences between the results and those given by Mr. Clark. In the majority of cases in practice, the slide rule is sufficiently accurate for making these calculations.

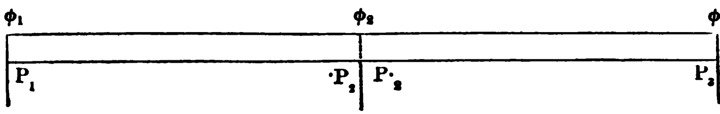
14. In simpler cases, such as that of the Torksey Bridge, investigated by Mr. Pole,[1] (M. Inst. C.E.,) the formulæ given above will be found to bring out the results with great ease and rapidity. As an example, however, one of the bridges on the Madras Railway, which presents the same features, though on a smaller scale, may be taken. The bridge over the River Cauvery consists of twenty-two openings, each 64 feet in span, with piers 6 feet in width, making the distance from centre to centre of the piers, 70 feet. The superstructure consists of a double line of wrought-iron boiler-

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. ix., page 257, *et seq.*

plate girders, each 140 feet long and 4 feet deep. Each such length rests on three bearing points, being fastened to the middle one, and free to move at the two ends. The strain and the deflections of this girder will now be examined; first, when both spans are loaded; and secondly, when one only is loaded.

For the sake of simplicity, let it be supposed, as in the case of the Britannia Tube, that the spans are brought close together, and the breadth of the pier diminished to a line, or edge.

Fig. 4.



Then, in the first case,

$$l_{12} \quad l_{23} = 64$$

$\mu_{12} = \mu_{23}$ = half the weight of the structure per foot run + half the rolling load $= 0{\cdot}166 + 0{\cdot}5$

$= 0{\cdot}666$ tons

also, $\quad \mathrm{EI} = 1{,}356{,}000.$

The general equation (7) then becomes

$$16\, l_{12}\, \varphi_2 = 2\, \mu_{12}\, l^3_{12}$$

$$\varphi_2 = \frac{\mu_{12}\, l^2_{12}}{8} = \frac{0{\cdot}666 \times 64^2}{8} = 336$$

$$\mathrm{P}_1 = \frac{\mu_{12}\, l_{12}}{2} - \frac{\varphi_2}{l} = 21{\cdot}33 - 5{\cdot}25 = 16{\cdot}08$$

$$\cdot\mathrm{P}_2 = \qquad = 21{\cdot}33 + 5{\cdot}25 = 26{\cdot}78$$

$$\mathrm{P}_3 = \mathrm{P}_1 = 16{\cdot}08 \qquad \mathrm{P}_2 \doteq 2\cdot\mathrm{P}_2 = 53{\cdot}56.$$

For the points of contrary flexure, the general equation (15) becomes

$$x = \frac{\mathrm{P}_1 \pm \sqrt{\mathrm{P}_1^2}}{\mu_{12}} = 0, \text{ and } 48{\cdot}24 \text{ feet from point 1.}$$

For the deflection at the middle of span, the general equation (10) becomes

$$y = \frac{l^3_{12}}{384\ \mathrm{EI}}\left(24\ \mathrm{P}_1 - 7\ \mu_{12}\ l_{12}\right),$$

which, by substituting the above values, gives

$$y = 0{\cdot}045 \text{ feet} = 0{\cdot}54 \text{ inch.}$$

In the second case, where one span only is loaded, $\mu_{23} = 0{\cdot}166$, the other quantities being as before. The general equation (7) then becomes

$$16\, l\, \varphi_2 = \left(\mu_{12} + \mu_{23}\right) l^3$$

$$\varphi_2 = \frac{\mu_{12} + \mu_{23}}{16}\, l^2 = 213$$

$$\begin{aligned}
P_1 &= \frac{\mu_{12}\, l}{2} - \frac{\varphi_2}{l} = 21{\cdot}333 - 3{\cdot}333 = 18 \\
{\cdot}P_2 &= \qquad\qquad\;\; = 21{\cdot}333 + 3{\cdot}333 = 24{\cdot}67 \\
P{\cdot}_2 &= \frac{\mu_{23}\, l}{2} + \frac{\varphi_2}{l} = \;\; 5{\cdot}333 + 3{\cdot}333 = \;\; 8{\cdot}67 \\
P_3 &= \qquad\qquad\;\; = \;\; 5{\cdot}333 - 3{\cdot}333 = \;\; 2
\end{aligned}$$

$$P_2 = {\cdot}P_2 + P{\cdot}_2 = 33{\cdot}34.$$

For the point of maximum strain in span 1.2, the general equation (13) becomes

$$x = \frac{P^1}{\mu_{12}} = \frac{18}{0{\cdot}666} = 27 \text{ feet from point 1.}$$

For the amount of maximum strain, the general equation (14) becomes

$$\varphi = \frac{\mu_{12}}{2} x^2 - P_1\, x$$

putting $\qquad x = 27, \qquad \varphi = -\,243.$

For the point of contrary flexure,

$$x = \frac{2\, P_1}{\mu_{12}} = 54 \text{ feet from point 1.}$$

For the deflection at the centre of span, proceeding as before,

$$y = 0{\cdot}0685 \text{ feet} = 0{\cdot}822 \text{ inch.}$$

Now, the weight of the unloaded bridge is just one-fourth of that of the loaded bridge. The deflection, therefore, when unloaded, will be one-fourth of that when loaded, or $\frac{0{\cdot}54}{4} = 0{\cdot}135$ inch, in the middle.

The difference between this and that last determined, 0·822 − 0·135 = 0·687, is, evidently, the deflection from its ordinary position, which should be occasioned by the passage of a rolling load of 0·5 ton to the foot run.

The actual deflection caused by the passage of a train of locomotives over a pair of these girders, erected for the purpose of the experiment in the station yard at Madras, was, on the mean of two trials, 0·755 inch. The weight was, however, a little in excess of a ton to the foot, or half a ton to each girder, and some slight further allowance should be made for the concentration of a portion of the weight on the driving wheels.[1] As these girders have been referred to, a peculiarity in their construction may be mentioned, which, as far as the Author is aware, was, at the time, new. For convenience of transport, the large beams, 140 feet in length, had to be made in several pieces, and the question arose, where the joints should be made.

The points fixed upon were at 52 feet distance from the supports 1 & 3, or about the mean between the positions of the point of contrary flexure, in the two conditions of the beam above considered. In neither case is the joint more than 2 feet distant from this point; consequently, the transverse strains are exceedingly small in both. In the case, however, of the unloaded half of the girder, in the second illustration, the point of contrary flexure recedes very considerably from the joint, and in fact, comes very near the bearing 3. It is desirable, therefore, to see to what amount of cross strain the joint may, probably, be exposed. Suppose the beam to be reversed, or turned right for left, then, at 52 feet from 3,

$$\varphi = \frac{\mu_{23}}{2} \times 52^2 - P_3 \times 52$$

$$= \frac{0{\cdot}166}{2} \times 52^2 - 2 \times 52 = 121,$$

This corresponds to a strain of 1·8 ton per square inch on the top and bottom fibres.

A more accurate examination, however, taking into account the breadth of the pier, showed, that the strains could not exceed 1·23 ton per square inch.

15. As a curious case, the strains and pressures at the supports

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[1] A subsequent and more exact calculation of I, in which the loss of section from the rivet holes is taken into account, gives 1,264,000 for the value of EI, instead of 1,356,000, as above. The effect of this would be to increase the calculated deflection 0·687, by about one-thirteenth. It thus becomes 0·74, or almost exactly the observed deflection.

of a continuous rail of infinite length, supported at equal intervals of 3 feet, and loaded with a given weight at the centre of one of the spans, taking also into account the effect of the weight of the rail itself, will now be examined. Let the weight per yard of the rail be 75 lbs., or 0·0335 ton, and let the load be 5 tons; then, numbering the bearings from the one on the left of the load, and adopting the previous notation,

$$32\,\varphi_2 + 8\,\varphi_1 + 8\,\varphi_3 = 4\,\mu\,l^2 + 3\,W\,l,$$

observing, that φ_1 evidently is equal to φ_2, and taking dimensions in inches:—

$$40\,\varphi_2 + 8\,\varphi_3 = 4{\cdot}8 + 540 \quad = 544{\cdot}8$$

or,

$$5\,\varphi_2 + \varphi_3 = 0{\cdot}6 + 67{\cdot}5 = 68{\cdot}1$$

also,

$$\begin{aligned} 4\,\varphi_3 + \varphi_2 + \varphi_4 &= 0{\cdot}6 \\ 4\,\varphi_4 + \varphi_3 + \varphi_5 &= 0{\cdot}6 \\ 4\,\varphi_5 + \varphi_4 + \varphi_6 &= 0{\cdot}6, \text{ \&c.} \end{aligned}$$

Hence,

$$\begin{aligned} \varphi_2 + 0{\cdot}2\ \ \varphi_3 &= 13{\cdot}62 \\ \varphi_3 + 0{\cdot}263\,\varphi_4 &= -\ 3{\cdot}48 \\ \varphi_4 + 0{\cdot}268\,\varphi_5 &= 1{\cdot}095 \\ \varphi_5 + 0{\cdot}268\,\varphi_6 &= -\ 0{\cdot}133 \\ \varphi_6 + 0{\cdot}268\,\varphi_7 &= 0{\cdot}197 \\ \varphi_7 + 0{\cdot}268\,\varphi_8 &= 0{\cdot}132 \\ \varphi_8 + 0{\cdot}268\,\varphi_9 &= 0{\cdot}125 \\ \varphi_9 + 0{\cdot}268\,\varphi_{10} &= 0{\cdot}127 \\ \varphi_{10} + 0{\cdot}268\,\varphi_{11} &= 0{\cdot}127, \text{ \&c.} \end{aligned}$$

After this there is no further variation in the coefficients, at least when only taken to three places of decimals, and consequently the successive φ's may be taken to be equal.

Hence, as $\varphi_9 = \varphi_{10}$,

then,

$$\begin{aligned} \varphi_9 = \varphi_{10} = \varphi_{11}\ \text{\&c.} &= 0{\cdot}100 \\ \varphi_8 &= 0{\cdot}098 \\ \varphi_7 &= 0{\cdot}106 \\ \varphi_6 &= 0{\cdot}169 \\ \varphi_5 &= -\ 0{\cdot}178 \\ \varphi_4 &= 1{\cdot}143 \\ \varphi_3 &= =\ 3{\cdot}782 \\ \varphi_2 &= 21{\cdot}184 \end{aligned}$$

Hence,

$$\left.\begin{aligned} {}^{\cdot}P_2 &= 0{\cdot}017 + 2{\cdot}5 = 2{\cdot}517 \\ P^{\cdot}_2 &= 0{\cdot}017 + \frac{24{\cdot}96}{36} = 0{\cdot}711 \end{aligned}\right\} P_2 = 3{\cdot}228 \text{ down}$$

$$\left.\begin{aligned} {}^{\cdot}P_3 &= 0{\cdot}017 - \frac{24{\cdot}96}{36} = -0{\cdot}677 \\ P^{\cdot}_3 &= 0{\cdot}017 - \frac{4{\cdot}923}{36} = -0{\cdot}120 \end{aligned}\right\} P_3 = -0{\cdot}797 \text{ up}$$

$$\left.\begin{aligned} {}^{\cdot}P_4 &= \qquad = 0{\cdot}154 \\ P^{\cdot}_4 &= 0{\cdot}017 + \frac{1{\cdot}321}{36} = 0{\cdot}054 \end{aligned}\right\} P_4 = 0{\cdot}208 \text{ down}$$

$$\left.\begin{aligned} {}^{\cdot}P_5 &= \qquad = -0{\cdot}020 \\ P^{\cdot}_5 &= 0{\cdot}017 - \frac{0{\cdot}347}{36} = 0{\cdot}007 \end{aligned}\right\} P_5 = -0{\cdot}013 \text{ up}$$

$$\left.\begin{aligned} {}^{\cdot}P_6 &= \qquad = 0{\cdot}027 \\ P^{\cdot}_6 &= 0{\cdot}017 + \frac{0{\cdot}063}{36} = 0{\cdot}019 \end{aligned}\right\} P_6 = 0{\cdot}046 \text{ down}$$

$$\left.\begin{aligned} {}^{\cdot}P_7 &= \qquad = 0{\cdot}015 \\ P^{\cdot}_7 &= 0{\cdot}017 + \frac{0{\cdot}008}{36} = 0{\cdot}017 \end{aligned}\right\} P_7 = 0{\cdot}032$$

$$\left.\begin{aligned} {}^{\cdot}P_8 &= \qquad = 0{\cdot}017 \\ P^{\cdot}_8 &= \qquad = 0{\cdot}017 \end{aligned}\right\} P_8 = 0{\cdot}034, \text{ \&c., \&c.}$$

It thus appears, that a load of 5 tons placed on the middle of one of the spans of a rail weighing 75 lbs. per yard, exerts an appreciable influence in modifying the pressures and strains up to about the eighth bearing on either side; after which its effect is entirely imperceptible, and the pressures and strains become, sensibly, those simply due to the weight of the rail itself.

[APPENDIX.

APPENDIX.

EQUATION 16.

As the derivation of this may not be quite obvious, it is here given :—

From 1 to $\frac{l}{2}$:—

$$\mathrm{EI}\frac{d^2 y}{d x_2} = \phi_1 - \mathrm{P}_1 x + \mu \frac{x^2}{2} \quad \ldots \ldots \ldots \ldots \quad (1).$$

From $\frac{l}{2}$ to l:—

$$\mathrm{EI}\frac{d^2 y}{d x^2} = \phi_1 - \mathrm{P}_1 x + \mu \frac{x^2}{2} + \mathrm{W}\left(x - \frac{l}{2}\right) \quad \ldots \ldots \quad (2).$$

Integrating (1) :—

$$\mathrm{EI}\frac{d y}{d x} = \phi_1 x - \mathrm{P}_1 \frac{x^2}{2} + \mu \frac{x^3}{6} + \mathrm{EIT}_1 \quad \ldots \ldots \ldots \quad (3).$$

Integrating (2) :—

$$\mathrm{EI}\frac{d y}{d x} = \phi_1 x - \mathrm{P}_1 \frac{x^2}{2} + \mu \frac{x^3}{6} + \mathrm{W}\frac{x^2 - l x}{2} + \mathrm{C}.$$

When $x = \frac{l}{2}$, then the two last are the same :—

$$\therefore \ \mathrm{EIT}_1 = - \mathrm{W}\frac{l^2}{8} + \mathrm{C};$$

$$\therefore \ \mathrm{C} = \frac{w l^2}{8} + \mathrm{EIT}_1 \ ;$$

$$\therefore \ \mathrm{EI}\frac{d y}{d x} = \phi_1 x - \mathrm{P}_1 \frac{x^2}{2} + \mu \frac{x^3}{6} + \mathrm{W}\left(\frac{x^2 - l x}{2} + \frac{l^2}{8}\right) + \mathrm{EIT}_1 \,(4).$$

Integrating again (3) :—

$$\mathrm{EI}y = \phi_1 \frac{x^2}{2} - \mathrm{P}_1 \frac{x^3}{6} + \mu \frac{x^4}{24} + \mathrm{EIT}_1 x.$$

Integrating again (4) :—

$$\mathrm{EI}y = \phi_1 \frac{x^2}{2} - \mathrm{P}_1 \frac{x^3}{6} + \mu \frac{x^4}{24} + \mathrm{W}\left(\frac{x^3}{6} - \frac{l x^2}{4} + \frac{l^2 x}{8}\right) + \mathrm{EIT}_1 x + \mathrm{C}_1 \quad (6);$$

but when $x = \frac{l}{2}$ (5) and (6) are the same ;—

$$\therefore - \mathrm{C} = \mathrm{W}\left(\frac{l^3}{48} - \frac{l^3}{16} + \frac{l^3}{16}\right) = \mathrm{W}\frac{l^3}{48};$$

$$\therefore \ \mathrm{EI}y = \phi_1 \frac{x^2}{2} - \mathrm{P}_1 \frac{x^3}{6} + \mu \frac{x^4}{24} + \mathrm{W}\left(\frac{x^3}{6} - \frac{l x^2}{4} + \frac{l^2 x}{8} - \frac{l^3}{48}\right) + \mathrm{EIT}_1 x;$$

but when $x = l \ y = o$:—

$$\therefore \ o = \phi_1 \frac{l^2}{2} - \mathrm{P}_1 \frac{l^3}{6} + \mu \frac{l^4}{24} + \mathrm{W}\frac{l^3}{4} + \mathrm{EIT}_1 l;$$

$$\therefore \text{EIT}_1 = -\phi_1 \frac{l}{2} + \text{P}_1 \frac{l^2}{6} - \mu \frac{l^3}{24} - \text{W} \frac{l^2}{48};$$

$$\therefore \text{EI}y = \phi_1 \frac{x^2 - l x}{2} - \text{P}_1 \frac{x^3 - l^2 x}{6} + \mu \frac{x^4 - l^3 x}{24} + \text{W} \left(\frac{x^3}{6} - \frac{l x^2}{4} + \frac{5 l^2 x}{48} - \frac{l^3}{48} \right).$$

When $x = \frac{l}{2}$:—

$$y = \frac{1}{\text{EI}} \left(-\phi_1 \frac{l^2}{8} + \text{P}_1 \frac{l^3}{16} - \mu \frac{7 l^4}{384} - \text{W} \frac{l^3}{96} \right)$$

For span 2.3 :—

$$\text{EIT}_2 = -\phi_2 \frac{l_{23}}{2} + \text{P}'_2 \frac{l_{23}^2}{6} - \mu_{23} \frac{l_{23}^3}{24} - \text{W}_{23} \frac{l_{23}^2}{48} \quad \ldots\ldots\ldots\ldots \quad (7).$$

Similarly for span 1.2 :—

$$-\text{EIT}_2 = -\phi_2 \frac{l_{12}}{2} + {}'\text{P}_2 \frac{l_{12}^2}{6} - \mu_{12} \frac{l_{12}^3}{24} - \text{W}_{12} \frac{l_{12}^2}{48} \quad \ldots\ldots\ldots \quad (8):$$

$$\text{but } \text{P}'_2 = \frac{\mu_{23} l_{23} + \text{W}_{23}}{2} + \frac{\phi_2 - \phi_3}{l_{23}}$$

$$\text{and } \text{P}_1 = \frac{\mu_{12} l_{12} + \text{W}_{12}}{2} + \frac{\phi_2 - \phi_1}{l_{12}}$$

adding (7) and (8), and reducing :—

$$16 \left(l_{12} + l_{23} \right) \phi_2 + 8 l_{12} \phi_1 + 8 l_{12} \phi_3 = 2 \mu_{12} l_{12}^3 + 2 \mu_{23} l_{23}^3 + 3 \text{W}_{12} l_{12}^2 + 3 \text{W}_{23} l_{23}^2.$$

As a verification of Equation (16), the result obtained by it may be compared with the case investigated by Moseley, in his "Mechanical Principles of Engineering and Architecture." Article 379.

In this case it becomes

$$16 \left(l_{12} + l_{23} \right) \phi_2 = 3 \text{W}_{12} l_{12}^2 + 3 \text{W}_{23} l_{23}^2;$$

$$\therefore \phi_2 = \frac{3 \text{W}_{12} l_{12}^2 + 3 \text{W}_{23} l_{23}^2}{16 \left(l_{12} + l_{23} \right)}.$$

$$\text{(A)} \quad \text{P}_1 = \frac{\text{W}_{12}}{2} + \frac{\phi_2}{l_{12}} = \frac{\text{W}_{12} l_{12} \left(8 l_{23} + 5 l_{12} \right) - 3 \text{W}_{23} l_{23}^2}{16 l_{12} \left(l_{12} + l_{23} \right)}$$

$${}'\text{P}_2 = \frac{\text{W}_{12}}{2} - \frac{\phi_2}{l_{12}}$$

$$\text{P}'_2 = \frac{\text{W}_{23}}{2} + \frac{\phi_2}{l_{23}}.$$

$$\text{(B)} \quad \text{P}_3 = \frac{\text{W}_{23}}{2} - \frac{\phi_2}{l_{23}} = \frac{\text{W}_{23} l_{23} \left(8 l_{12} + 5 l_{23} \right) - 3 \text{W}_{12} l_{12}^2}{16 l_{23} \left(l_{12} + l_{23} \right)};$$

adding together $'\text{P}_2$ and P'_2, substituting and reducing :—

$$\text{(C)} \quad \text{P}_2 = \frac{1}{2} \left\{ \text{W}_{12} \left(1 + \frac{3 l_{12}}{8 l_{23}} \right) + \text{W}_{23} \left(1 + \frac{3 l_{23}}{8 l_{12}} \right) \right\},$$

Expressions (A), (B), and (C), being identical with Moseley's, 576, 577, and 578.

These expressions are only used for the purpose of comparison. To obtain the numerical results in any particular case the process is very much more simple; thus suppose

$$l_{12} = 10 \text{ feet } l_{23} = 15 \text{ feet},$$

$$W_{12} = 6 \text{ tons } W_{23} = 8 \text{ tons},$$

then
$$\varphi_2 = \frac{3 \times 6 \times 10^2 + 3 \times 8 \times 15^2}{16 \times 25} = 18.$$

$$P_1 = \frac{6}{2} - \frac{18}{10} = 1{\cdot}2;$$

$$\left.\begin{array}{l} {}'P_2 = \frac{6}{2} + \frac{18}{10} = 4{\cdot}8 \\ {}'P_2 = \frac{8}{2} + \frac{18}{15} = 5{\cdot}2 \end{array}\right\} P_2 = 10;$$

$$P_3 = \frac{8}{2} - \frac{18}{15} = 2{\cdot}8.$$

Britannia Tube.

The general equation (8) for spans 1.2, and 2.3, becomes

$$8\left(l_{12} + \iota_2 l_{23}\right)\varphi_2 + 4\,\iota_2 l_{23}\varphi_3 = \mu_{12} l_{12}^3 + \iota_2 \mu_{23} l_{23}^3$$

$l_{23} =$	460		2·6628
$\iota_2 =$	0·607324		$\bar{1}$·7834
$\iota_2 l_{23} =$		279·4	2·4462
$l_{12} =$		230·0	
		509·4	
		8	
		4,075·2 = coefficient of φ_2.	
$\iota_2 l_{23} =$		279·4	
		4	
		1,117·6 = coefficient of φ_3	
l_{23}			2·6628
l_{23}^3			7·9884
$\mu_{23} =$	3·38		·5289
ι_2			$\bar{1}$·7834
		199,850,000	8·3007
l_{12}			2·3617
l_{12}^3			7·0851
$\mu_{12} =$	2·6		·4150
		31,630,000	7·5001
		231,480,000 absolute term.	

To clear of coefficient of φ_2 :—

	1,117·6	3·0483
	4,075·2	3·6101
	0·2743	$\bar{1}$·4382
Coefficient of φ_2,	231,480,000	8·3645
		3·6101
absolute term,	56,810	4·7544

$$\varphi_2 + 0{\cdot}2743\ \varphi_3 = 56{,}810$$

The general equation (8) for spans 2.3, and 3.4, becomes, remembering that $\varphi_2 = \varphi_4$ and $l_{23} = l_{32}$,

$$16\, l_{23}\, \varphi_3 + 8\, l_{23}\, \varphi_2 = 24\ \mathrm{EI}t_3 + 2\, \mu_{23}\, l^3_{23}$$

or,
$$2\ \varphi_3 + \varphi_2 = \frac{12\ \mathrm{EI}t_3 + \mu_{23}\, l^3_{23}}{4\, l_{23}}$$

l^3_{23}		7·9884
μ_{23}		·5289
	329,080,000	8·5173
$t_3 = -\ 0{\cdot}00409$ 7/		$\bar{3}$·6096
$\mathrm{I} = 1{,}584$		3·1998
$\mathrm{E} = 10{,}000$		4·0000
× 144		2·1584
12		1·0792
	− 111,430,000	8·0470
	217,650,000	8·3377
$4\, l_{23} = 1{,}840$		3·2648
$2\ \varphi_3 + \varphi_2 =$	118,250	5·0729

The equations (5) and (6) for span 1, 2, become

$$\mathrm{P}_1 = \frac{\mu_{12}\, l_{12}}{2} + \frac{-\ \varphi_2}{l_{12}}$$

$$\mathrm{P}_2 = \frac{\mu_{12}\, l_{12}}{2} + \frac{\varphi_2}{l_{12}}$$

$-\ \varphi_2 = -\ 47{,}030$		4·6724
$l_{12} = 230$		2·3617
	204·5	2·3107

l_{12}		2·3617
μ_{12}		·4150
		2·7767
2		3010
	299·0	2·4757

94·5 = difference P_1,
503·5 = sum $\cdot P_2$.

The equations (5) and (6) for span 2.3, become

$$P\cdot_2 = \frac{\mu_{23} l_{23}}{2} + \frac{\phi_2 - \phi_3}{l_{23}}$$

$$\cdot P_3 = \frac{\mu_{23} l_{23}}{2} + \frac{\phi_3 - \phi_2}{l_{23}}$$

ϕ_2 = 47,030			
ϕ_3 = 35,610			
	11,420		4·0577
l_{23}			2·6628
		24·8	1·3949
l_{23}			2·6628
μ_{23}			5289
2			3·1917
			3010
		777·5	2·8907

802·3 sum $P\cdot_2$,
752·7 difference $\cdot P_3$.

No. 1,028.—"On Breakwaters." Part. II.[1] By MICHAEL SCOTT, M. Inst. C.E.

IN December, 1858, a Paper by the Author was read before the Institution, "On the Breakwater at the Port of Blyth, and Improvements in Breakwaters, applicable to Harbours of Refuge,"[2] which gave rise to a long and animated discussion. Having been requested to contribute another Paper, in continuation of this subject, and believing that a notice of the portion of the Blyth Breakwater, which has been completed since the date of the previous communication, will be interesting to the Institution, the Author gladly acceded to the request.

It was originally intended, that the present Paper should contain a discussion of some important questions, relating to harbours, including entrances, jetties, and quays; but it has been considered best to postpone this part of the subject to another opportunity.

THE COMPLETION OF THE BLYTH WORK.—To quote the words of the former Paper:—"In the case of the portions of the Blyth Pier just referred to, the site was either dry, or nearly so, at low-water spring-tides; but the line upon which it was to be continued, led into a depth of 5 feet, or 6 feet, at lowest spring-tides, and about 22 feet at high-water spring-tides."[3] During last year, this extension was carried out, and the breakwater has been completed, with entire success. After the particulars given in the former Paper, it will be unnecessary to enter into any lengthened description of the part of the work now referred to; it will be sufficient to direct attention to one, or two points of importance. In the course of the discussion on the former Paper, the two main objections to this system of constructing a breakwater of timber and stone, were the assumed difficulty of erecting large frames in deep water, and an alleged deficiency in strength, when completed. It does not often happen, that the experience of a single season affords so complete an answer to both of these objections.

First; as to the difficulty of erecting frames in deep water. The frames at Blyth are 10 feet apart from centre to centre; but

[1] The discussion upon this Paper was resumed on the first evening of the following Session, 1860-61, but an abstract of the whole is given consecutively.

[2] *Vide* Minutes of Proceedings Inst. C.E., vol. xviii., p. 72.

[3] *Ibid.*, p. 74.

notwithstanding this projection of each successive frame beyond the end of the work, and of the existence, at times, of a cross current of about $3\frac{1}{2}$ miles per hour, they were erected with the greatest ease, and generally, between half-tide and high water. So far from a still greater depth of water being any objection, it is believed, that it would facilitate the work. The Author, therefore, considers, that there is no longer room for doubt, that the work described last year, and designed for erection in 10 fathoms of water, could be constructed with expedition and success. It should be remembered, that in the larger work, the frames are only 6 feet apart, instead of 10 feet, as at Blyth.

The method by which the panels of planking, which were fixed with great facility, were hauled down under water, was somewhat novel. At each end of the panel, a hook was fixed, from which a hauling line was carried through a single block below, up to the water level. This block was held in position by another line attached to it, and passed through a staple, driven into the frame before being sunk, and temporarily made fast to the work above. There was a similar arrangement at each end of the panel. The panel being placed between two uprights, and the ropes made fast to it, by means of the hooks, it was hauled down to the bottom and secured; the upright bars serving, laterally, as guides. When the panel was fixed, the line was cast off, and the block and ropes were hauled to the surface. This system of planking was the most suitable in such cases as Blyth, but the Author would not recommend it for adoption in deep water; for not only would the large panels be difficult to handle, but this form of construction is not so strong as the arrangements formerly described.

With respect to the time occupied in the erection of a work of this description, the experience at Blyth shows, that two frames, or 20 lineal feet of breakwater, could be completed per day during the season. With regard to cost, it has been proved beyond doubt, that the system of depositing frames is much cheaper than piling.

Secondly; as regards strength. The power of the sea on the coast of Northumberland during a storm, is so well known, that it is unnecessary to adduce proofs of the fact. As formerly mentioned, the long fetch of the North Sea must, occasionally, produce a very heavy sea, and yet the weakest part of the work described, has now been exposed for four winters, without injury. The storm which occurred on the 25th of October, 1859, was stated to be the most severe that had been felt on the eastern coast, for many years; and the damage done to many sea works attests the truth of the statement. But although a tremendous sea broke against the Blyth breakwater, it was not injured in the slightest degree. An important consideration, which should not be lost

sight of, for it affects both the questions of facility of construction and of strength, is, that the frames at Blyth are 10 feet apart; whereas in the designs exhibited last year, which were objected to as deficient in strength, the frames were only 6 feet apart, which would, of course, render the work proportionately stronger than that at Blyth. The Author is still of opinion, that such breakwaters are stronger, and that they can be erected for less money and in less time, than any arrangement previously in use. The round end constitutes an elegant termination to the breakwater, and has proved, as was anticipated, to be a work of great strength. The planking is interlaced in such a manner, that the planks become a series of hoops, tending to bind the whole work together, and imparting great strength, in proportion to the material employed. Scarcely any difficulty was experienced in the erection of this part of the work. The cost per lineal foot of the breakwater, including the round end and the lighthouse, was about £11.

The Author would again refer to the importance of saving time in construction; for surely, the time which is required to inclose a harbour, is a matter of the greatest consequence. Every year saved represents not only commercial advantages, but, in refuge harbours, life itself. Now the system of construction described, possesses these qualifications in an eminent degree. The harbour is speedily inclosed, and a large saving of money is effected, by deferring an important part of the expenditure.

It might have been thought impossible to question the rigid correctness of this principle. But it has been questioned; and therefore, the Author would refer to the Tables printed with the former Paper,[1] to the evidence given by him, last year, before the Royal Commission on Harbours of Refuge, to their Report thereon, and to the Author's reply, by which it was clearly proved, that by erecting a breakwater, like those described, in the first instance, and subsequently, removing the timber, and facing the work with stone, the result would be a considerable saving both in time and money. With regard to the durability of creosoted timber, it may be stated, that whilst at Blyth, the timber in its natural condition is rapidly destroyed by the worm, the creosoted timber has undergone no change during the past four years.

Proposed Form of Breakwater.—Whilst such arrangements, as have been described, present many advantages, there are situations to which neither they, nor any ordinary kind of breakwater, would be applicable, and conditions which none of them

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xviii., pp. 154-158.

fulfil. It was the consideration of this point, which led to the designing of the breakwater now to be described.

In order to explain the advantages which are claimed for this work, it is necessary to advert to certain questions of principle involved in the formation of harbours, and in the construction of breakwaters. As it will be unnecessary to repeat all that was advanced upon the subject in the previous Paper, and as it is intended to avoid nautical and commercial questions, so far as possible, attention will only be directed to the following points, which should be kept in view by the Engineer:—

First; A desirable site, offering sufficient area and depth of water, having been pointed out, the facility for obtaining suitable materials for constructing the breakwater, becomes the principal question.

Secondly; Although the direction of the entrance, or entrances, is chiefly a nautical question, and may be considered as partly included in that of suitability of site, yet the Engineer must have regard to it, as it affects his work, and it might, for example, involve silting.

Thirdly; The object of a harbour being to afford shelter from the sea, the inclosing work will be efficient, in proportion as it produces freedom from undulation in the harbour.

Fourthly; The depth of water in the harbour must be maintained, and silting prevented, as far as possible. Then with regard to the inclosing work, or breakwater, the following considerations will weigh with the Engineer, in addition to those previously mentioned.

What is the magnitude of the waves to be encountered, and will they be so large, or the depth so limited, that the waves will break on the work?

How can the work be most rapidly executed?

Is it possible to apply mortar work, in place of dry work, the former being so much stronger?

Having premised thus much, the Author will refer, for illustration, to a well-known instance, in which great difficulty has been experienced in designing a suitable breakwater, and to which none of the forms hitherto employed would appear to be applicable, —Table Bay, Cape of Good Hope. In this case, the principal difficulties arise from the immense magnitude of the rollers, which are waves of the first order, or waves of translation, and from the risk of silting, which there is reason to apprehend, would be produced by the current round the bay.

A brief notice of the leading peculiarities of the ordinary forms of breakwater, will suffice to show, whether any one of them would meet the requirements in the above instance. The first form of breakwater, taken in the order of time of its introduction, is the

slope, of which the work at Plymouth is a type. (Plate 8). The advantage which may be claimed for this form, where stone is very abundant in the immediate vicinity, is the supposed cheapness; but this advantage is neutralised, to a great extent, by the necessity for employing large blocks of dressed stone, to form the face of the slope. From the great quantity of stone used, it really becomes costly to construct, and is expensive to keep in repair; and, except in special cases, it is not so efficient as some other forms, as the sea partly rolls over it, producing disturbed water inside, which would be seriously felt in a harbour of limited area. It is clear, that for the situation in view, even although rough stone be abundant and cheap, this form would not be suitable.

The second form, is the vertical wall on a rubble bank, the bank sloping from low-water mark downwards to the bottom, like the breakwater at Alderney. (Plate 8.) This form would be objectionable, because the waves would break on the work; and how far it would be likely to stand the blows of the tremendous seas at the Cape, is problematical. It would be objectionable in a minor degree, because it requires squared and well-set stones in the face of the wall, which, together with the necessity of building from one end, renders it expensive and tedious in construction; and this form would not prevent silting.

The same observations apply to the third form, which is that adopted at Holyhead, and also at Portland, (Plate 8,) where there is a vertical wall on a rubble bank, which slopes from a few feet above high water downwards. If such a work failed to resist the seas at Table Bay, not only would the breakwater be destroyed, but the harbour would be ruined, by the large stones being strewed over the anchorage. Of course, this form is only applicable where stone is abundant, and even then, it becomes a tedious and comparatively expensive work.

The fourth form is the vertical wall, built either from the bottom, or from the depth below low water, at which the action of the waves ceases to be felt; the pier at Dover, (Plate 8,) is an example of the former. These two modifications are both correct in principle, when the sea is unbroken. But in the locality referred to, Table Bay, the waves are said to be breaking waves; and even if they were not, the height of the wall above high water, necessary to receive the rise of such enormous waves, would render this form inapplicable. Moreover, the hydrostatic pressure of the water against so high a wall, would require great width of structure to afford the necessary stability. For, it must be remembered, that a wave rises against a vertical wall to twice its height; and if the wall is not high enough, unbroken water is sent over into the harbour, doing damage on its way, and reproducing a wave inside. Neither of these forms would prevent silting.

It would, consequently, appear, that none of the ordinary kinds of breakwater would be applicable to Table Bay; and none of them would provide in any way against the silting up of the harbour and entrance, a point of importance, not only in Table Bay, but in other situations.

The Author has now to submit to the notice of the Institution, the proposed new kind of breakwater, (Plate 8,) which, it is believed, will be found to possess several advantages, and which, he thinks, would be applicable in such localities as the Cape. It will be observed, that it is a modification of the wave screen, described in the Paper contributed by the Author in 1858. But whilst the same principle is involved, the new arrangement differs from the screen of 1858, in some important particulars, such as being applicable in deep water, &c. In the case of deep water, and where stone is to be readily obtained, a bank of rubble might be deposited, rising to within, say 15 feet, or more, of low-water mark, the height of the bank varying with the circumstances of the locality. Upon this bank it is proposed to build a face wall, up to low-water mark, and behind this wall, long counterforts, the upper surface of which would rise from low water, at an inclination of about 2 to 1, and extend back for a distance dependent upon the amount of slope, rendered necessary by the magnitude of the waves. These counterforts would be placed at sufficient intervals, say of 20 feet, as to be conveniently spanned by iron girders, and the whole of the sloping surface would be converted into a sort of gridiron, by girders laid from pier to pier, the upper flanges being about 1 foot wide, and the girders laid at intervals of about 18 inches.

Supposing such a breakwater to be erected and exposed to a heavy sea, if the waves are not breaking, the water would be projected up the slope, and would drop through the spaces between the girders; and if the waves are breaking, they will rush up the slope as a confused mass of water, dropping through on their passage. But, although it is anticipated, that the great bulk of the water would pass through the grating, and not return to the foot of the slope, the operation would be gradual and be diffused over a considerable surface, so that a wave would not be reproduced inside. The only effect would be a stream of water into the harbour, and in this particular, the proposed form differs in principle from all vertical screens, or gratings, which, by permitting the waves to pass through, at the same instant of time, have not the effect of destroying the undulation. The breakwater should, if possible, be placed at an angle with the direction of the greatest sea, so that a wave should not only run up the slope, but along it, diffusing itself in this manner, over a much larger area; and this would be especially desirable in a case like Table Bay, where the waves are of such

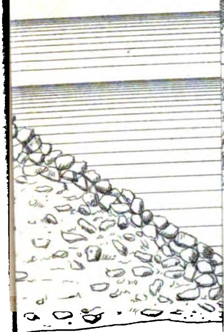
magnitude. It is supposed, that this form of breakwater possesses further advantages; it would not only be efficient as a breakwater, but it would also, in the opinion of the Author, be sufficiently strong to resist waves which would probably wreck any other form, arranged to afford equal protection. Moreover, it will be observed, that the surface exposed to the blows of the waves, is covered with mail, so to speak, and could not be disintegrated. It would be durable, for the iron is not of the nature of thin plates readily destroyed by oxidation; but it is in solid masses, the whole of which is above water, and could, therefore, be preserved by painting. From its simplicity, it would be easily and quickly constructed. The face wall and counterforts might be formed of large rubble blocks prepared on shore. The risk of interruption to the progress of the work, would then be confined to the period during which the blocks were being deposited; and with the facilities described in the former Paper, a great length of breakwater might be erected in a single season. It should also be noticed, that as each counterfort constitutes a complete and separate work, the risk of damage, by storms during erection, is reduced to a minimum. It would be cheap, and it would cost considerably less than the breakwaters at Dover, Alderney, Holyhead, or Portland. A breakwater for Table Bay would stand in water, on the average, about 7 fathoms deep. Calculated at prices current in this country, the cost of such a work, in 7 fathoms of water, would not amount to £80 per foot run. Moreover, whilst ordinary rubble work will withstand the action of the sea for an indefinite time, it requires the best work to resist the blows of the waves. In this respect, it will be obvious, that the new work possesses great advantages, so that comparatively inferior material might be employed with success in its construction. Again; in the case of the work being erected abroad, where skilled labour was scarce and expensive, the whole of the iron work, in a finished state, could be advantageously supplied from this country. Finally; and this is a novel feature of the new form, whilst it would operate successfully as a breakwater, it is thought, that it would tend to prevent the silting which arises from sand brought in by the tide.

This question, however is too important to be dealt with incidentally, and belongs to the next Paper, in which it will be discussed.

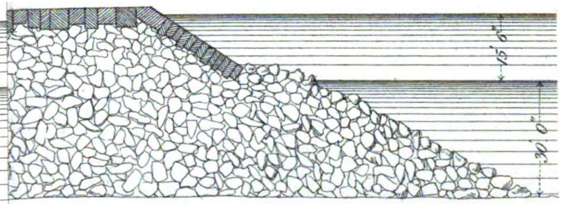
The Paper is illustrated by diagrams and models, from which Plate 8 has been compiled.

[Mr. J. Scott Russell

Harbour Face



Harbour Face



Sea

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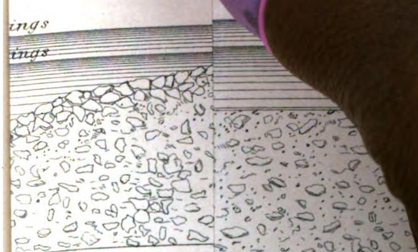

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Mr. J. Scott Russell said, that the former Paper had given rise to a valuable and interesting discussion. In the present Paper, the Author had recapitulated some of his arguments, and had confirmed his views of the efficiency of the breakwater at Blyth Harbour; he had also submitted a plan of a gridiron, or wave screen, on the top of a rubble bank, to stop the progress of the waves. It was difficult to estimate truly the effect, in general terms, of the proposed arrangement, without knowing the depth of water, the dimensions of the works, and the height and length of the sea, in which it was intended to be placed. It was also necessary to consider the various uses of breakwaters, the various nature of the action of the sea, and the various ways in which the difficulties were now met by engineering expedients, before it was possible to decide whether this plan was, or was not better for practical use, than those hitherto acted on.

On a former occasion, the late Mr. Rendel had wisely cautioned Engineers, that they must not imagine, because any one method had been successful under one state of circumstances, it would, necessarily, be successful elsewhere, under others; for every different locality and every different coast required, from the presence of materials, the nature of the sea, the conditions of the shore, and the prevalence of the winds, a construction of harbour peculiar to that place. Mr. Scott Russell, by experiments upon a moderate scale, and from observations wherever he had been able to make them, under circumstances approximate to the present case, had ascertained, that the progress of a wave of the first order was not retarded, by interposing an obstacle parallel to the ridge of the wave. Now it was proposed to substitute a wave screen, for the usual perpendicular, or sloping pier of masonry which formed the top of the breakwater. There were, no doubt, certain circumstances under which the propagation of a wave would be materially impeded by such a screen, and if another was placed at a certain distance behind it, so that the first might retard the wave till the superfluous water of it got into the hollow of the following wave, such an arrangement would be a great approximation towards preventing the continued propagation of the wave. But in sea works there were, practically, two classes of waves to deal with, of such different, if not, opposite natures, that what was beneficial in the one case, was often useless in the other. Now even supposing a structure of this kind to be durable, and economical in construction, it did not seem adapted to successfully resist a large ground swell, or wave of the first order, or wave of translation. There was every reason to believe, that the great ground swell of the Cape of Good Hope was of that character; solid columns of water, sometimes as high as 30 feet, rolling in with an enormous progressive motion, and giving to the water a vast force of horizontal translation, extending

to a great depth. The interposition of a screen, even 80 feet in length, as proposed, would scarcely stop the translation of one of these enormous waves, which would, probably, pass very nearly over it, as if it were a solid slope, because the openings would soon get filled. In other words, the quantity of water that could be forced, in a short time, through these openings, would not be sufficient to relieve the pressure of the enormous mass of superincumbent water, even on the most advantageous supposition, that the wave impinged upon the structure at right angles. But if the wave impinged obliquely upon it, it would receive upon every one of its counterforts such an enormous pressure, that it was impossible to conceive, that any ingenious combination of them would enable them to resist the attack. He would resume, in a few words, his views upon the system of gridirons, or wave screens of open timber and iron piling. They were, no doubt, efficient in a degree, but he was not able at present, to fully appreciate the value of their effect in relation to their cost. The momentum of the ground swell was not, however, to be destroyed by any structure of small weight and great specific cost, and vertical piles would not oppose resistance to the vertical part of the motion of oscillating waves. For waves of translation, a gridiron, or series of piles, would only offer resistance, proportioned to the number and distance of the rows of the piles placed behind each other, and to the length between them. In regard to wind waves, so long ago as 1847, he had presented to the Institution, a Paper "On the Practical Forms of Breakwaters, Sea Walls, and other Engineering Works exposed to the action of Waves,"[1] in which he expressed a strong opinion on the expediency of certain forms of section, very different from one another. Where the water was not deep, and the object was merely to render the surface oscillating waves harmless to the work on which they broke, the cycloidal form he then recommended was, as he still thought, well fitted for the purpose. By this form, the action of the waves was rendered tolerably equal over the whole surface, thereby diminishing the chance of special injury at any one point, and stones of a moderate size, uniformly distributed, were each enabled to bear their portion of the power of the wave, and so together to withstand, without injury, the whole shock of the surface waves. But this form was only suited for this limited purpose. It was chiefly applicable to long shallow fore shores, liable to a sharp, short, but severe, set of waves, breaking at moderate heights, on account of the shallowness of the water in the offing; the oscillating wave being merely allowed to rise and fall along the surface, with the least possible injury to the structure of the sea wall.

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. vi., p. 135.

But a true breakwater was a structure of a totally different nature, and designed for a totally different purpose, that of producing comparatively smooth water, not in the case of oscillating waves in shallow water, but of heavy waves and in deep water. Now in deep water, there were not only the oscillating surface waves to be encountered, but also those which he had termed waves of translation, forming what were called rollers at the Cape of Good Hope, and when on a smaller scale, known as ground swell. These were a much more troublesome class of waves; it was mainly with them that the Engineer had to deal, in places open to the Atlantic; and after a storm of some duration at sea, they became the deadliest enemies in the cases of deep water, against which breakwaters for harbours of refuge had to contend. These rollers, or ground swell, did not merely oscillate up and down, and backwards and forwards; and they could not be eluded, or turned back, by giving to the wall a particular curve, suited to the form of a cycloidal oscillation.

These great waves of translation constituted a vast mass of solid water, moving in one direction with great velocity, and this action was nearly as powerful at a great depth, as at the surface. They resembled the tidal bore of the Hooghly, of the Severn, or of the Dee; they formed a high and deep wall of water, of great weight, moving horizontally with great force, and causing all floating bodies they met with, to travel with them with great velocity, in the same direction. As he had before mentioned, they could not be eluded, or diverted, they must be stopped; and therein consisted the difficulty. The only certain way of effecting it, was to oppose to these waves a mass of matter so much heavier than themselves, that they could not move it. By so doing, the waves were compelled, either to roll over the obstacle, in which case they would create a new wave inside; or they must be made to break on themselves backwards, which required enormous power; or they must be completely reflected, which perhaps, required the greatest force of all.

To reflect, or send back the roller was the most effectual plan. For this purpose, nothing more was necessary than a deep perpendicular face of perfect masonry, and so long as it stood firm, it was faultless, and the water inside was smooth as in a millpond; for the reflection really converted the whole effect of the roller on itself, into a simple pressure of water. When such a wave was reflected on a perpendicular wall, it merely produced a hydraulic pressure, equal to that due to little more than double its own height. A roller, 20 feet in height, would produce a pressure of about a ton per foot, and it would be reflected by a vertical wall of moderate dimensions. He had, therefore, no hesitation in saying, that, cost apart, a wall of vertical masonry was the best, while it lasted. The primary cost of erecting a vertical wall of

perfect materials was, in most cases, so great, as to put it out of the question, setting aside the important point of durability, which was also cost in a serious form. A vertical wall of masonry had, however, this great disadvantage; if the sea found out a weak place, it would enlarge it much more rapidly than in an inclined wall. He had seen a stone of small size show symptoms of crumbling at the beginning of winter, and in one week the little hole of single defective stone was converted into a circular breach, nearly 30 feet in diameter. An inclined wall, he had ascertained, would reflect a roller, or deep wave, nearly as well as a vertical wall, down to an inclination of 45°. This observation was of value, because at 45°, large blocks, judiciously placed, would not move out of position, even although a considerable breach was made in the wall near them. He had carefully watched the action of the sea, when approaching this slope, and his opinion was favourable to the trial of a wall of heavy rubble blocks fairly laid, so as to form a tolerably even face, or slope of 45°, when the nature of the materials and the local circumstances would permit.

When any approximative attempt at reflection of the wave, by walls not too remote from the vertical, had to be abandoned, recourse must, generally, be had to breaking the wave. This was a formidable thing to attempt on a deep-sea roller; and it could only be done by opposing mass to mass. For this purpose, he had ventured to recommend, that the fore foot of the breakwater should be rounded off, and that the shape of the breakwater should be convex. The intention of this was, to cause the front wave to begin breaking at the earliest moment, to make the breaking last as long as possible, and thus to render the diminution of its momentum as complete as was practicable. In breaking a wave it was very important, that it should be made to break on the water, and not on the stones; and the convexities given to the foreshore accomplished this object, by causing the waves to begin breaking, as far out as possible in deep water. The form for breaking a deep roller, should be entirely distinct from that used for meeting a superficial oscillating wave; the one should be concave, the other convex. The Digue, or breakwater of Cherbourg,[1] showed an approximation to this form. A breakwater, to succeed in breaking the long waves of translation, rolling in from deep water after a storm, should have a long convex slope.

The practical construction of breakwaters was, however, scarcely confined either to resisting deep-sea rollers, or waves of translation, or to procuring the means of stopping the progress of common sea waves, or mere surface oscillation; it usually combined both of these objects. It might, therefore, be considered as

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xviii., plate 2.

the general problem of a breakwater; first, to stop out the great wave of translation, and secondly, to still the oscillating surface wave. A vertical wall effected both these conditions, and so also did a convex sea-slope, with a vertical pier. But the best plan of all was, first to carry up a convex sea-slope of rubble, to near the surface of the water, and thus break the force of the heavy ground swell, that would sweep ships from their anchors, and lay them high and dry on a lee shore. This would allow the wave to break to pieces on itself, and to expend its force in raising so much water as represented its momentum, to a height above its former place, sufficient to exhaust its power; in other words, to expend its power on water. Secondly, to carry up from the top of the rubble slope, a wall slightly inclined, to reflect the waves of oscillation near the surface, which could do no harm, if quietly resisted and sent back. This plan seemed to be that which had been found to answer best in practice. He further considered, that making a step backwards in the upper work of a breakwater, was of great value in preventing the tops of the waves from going over. He had carefully watched the effect at Marseilles, and his observation had confirmed the opinion he expressed in favour of it, in 1847.

These views of the nature of the forces to be resisted in breakwaters, and the methods of dealing with them, showed the inefficiency of what were called floating breakwaters. Large floating masses would, certainly, intercept oscillating waves of a small depth, and in moderate weather, they would often still the water. The lee side of the 'Great Eastern,' when lying at Holyhead, afforded excellent anchorage for small vessels, in light breezes. But when the great roller, the one great wave of translation came, the anchors snapped at once, showing the danger which would have been incurred, had she been moored broadside to the roller, instead of offering to it the small resistance of her fine bow. No known force could effectively secure a large floating breakwater broadside-on to a heavy ground swell. It would move horizontally with the wave of translation, which would propagate itself along the bottom, just the same as if the breakwater was not there.

Mr. Longridge thought it had been erroneously conceived, that this breakwater could be put down in blocks, at certain intervals; but the real intention appeared to be, to make it a continuous structure. He thought, that when a wave had once broken upon the breakwater, any propagation of it inside, would be of a very small and insignificant character. It would only consist of the quantity of water that passed through the grating; it could not, therefore, be a wave of translation; it would only be a wave of oscillation of a very minute character, which could not produce any injurious effect. But the distinction which had

been made between the two kinds of waves, was not satisfactory to his mind, so far as works of this nature were concerned; because the same work might, at one time of tide, meet waves of oscillation, and at another time, waves of translation. It could only be in very deep water, that pure waves of oscillation would occur. He did not see, how it was possible, in designing a breakwater for a given locality, to foresee where the wave of translation, and where the wave of oscillation would arise.

Mr. W. A. Brooks said, that he considered justice had not been done to the works of former Engineers. No notice had been taken, for instance, of Kingstown Harbour, constructed entirely upon the long-slope principle, the slopes being at 5 to 1, and the total cost having been only 1*s.* 6*d.* per ton, which amount had been exceeded by the cost of the scaffolding alone of some of the modern public harbours. The sections of breakwaters gave only that of the inner pier of Portland Harbour, which was partly constructed of vertical masonry, but the great breakwater was altogether constructed upon the long-slope system, and the present Engineer, Mr. Coode, (M. Inst. C.E.,) had given evidence, that he did not believe it would be necessary to construct any vertical masonry, except for quays, or wharves on the inside. Mr. Brooks considered Kingstown Harbour as a perfect work, for its locality, but for more exposed situations it might, probably, be necessary to increase the slope from 5 to 6, or even 7 to 1, near the level of high water of spring tides, where the stroke of the wave was the heaviest. He was satisfied with the soundness of the system of constructing deep-water piers with a long slope, in preference to vertical walls, and he entirely agreed with the arguments used by the advocates of that system, at the former discussion on the subject.[1] He regretted to say, that in the execution of modern harbours of refuge, the science of construction appeared to have retrograded, instead of advancing.

He was well acquainted with Blyth Harbour, and he was confident, that the pier which had been constructed there, could not, with propriety, be adduced as an example of the success of vertical walls, when exposed to a stormy sea. The pier was constructed on a ledge of rock, extending about 4,700 feet from the shore, and it covered about 4,400 feet of that length. The surface of the rock was from 10 feet to 6 feet above the level of low water of spring tides, and at the outer end, or seaward of the pier, the rock was 6 feet in height above low water. The seaward margin of the rock was called the 'Sow and Pigs,' and it was situated at the great distance of 1,100 feet from the foot of the pier constructed by Mr. J. Abernethy, (M. Inst. C.E.,) act-

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xviii., p. 91, *et seq.*

ing as a breakwater to protect the pier from heavy seas. The mass of rock on which the pier was built, had a breadth of about 400 feet seaward of the pier, between which and the Sow and Pigs rocks, or outer barrier, there was a pool from 5 feet to 8 feet deep at low water. Heavy seas broke at the distance of half a nautical mile from the line of pier. In addition to this great natural protection to the pier, offered by the presence of the rocks between it and the sea, there also existed, at a distance of 60 feet seaward of the pier, one of those old-fashioned, but useful long-slope piers, varying from 4½ feet to 1 foot in height, and this extended for a length of about 700 feet. He considered, that the Engineer who constructed Blyth Pier, was not warranted in treating it as one which was exposed to heavy seas; it was, however, a very cheap and proper work for the situation, and so far, did credit both to the Engineer and to the Contractor.

Mr. M. Scott expressed his dissent from the statements which had just been made, relative to Blyth.

Mr. J. Cockburn Curtis could not agree with the Author of the Paper, as to the adaptation of the form and structure of the breakwater under discussion, to the special conditions of Table Bay, Cape of Good Hope. Whilst in the Royal Navy he had been, for some years, on the Cape station, and on several other occasions he had visited Table Bay. He was, therefore, well acquainted with the physical features of this peculiar case. Table Bay might be described as a bight, or recess, with a northern aspect, on the eastern side of the mass of mountainous and rocky land, which formed the peninsula of the Cape of Good Hope. This peninsula was the turning point of the wind and wave systems of the Indian and Atlantic Oceans, and its littoral portions, including Table Bay, were, at certain periods, subject to all the sudden and violent atmospheric and oceanic changes incidental to such a situation. The circle of wind influence around the Cape of Good Hope, had been variously estimated to extend from 300 miles to 600 miles from the land, and hence the 'lead' of the waves, or the length which they travelled in the course of their development, before reaching Table Bay, might be taken to be of nearly equal extent. The prevailing winds in Table Bay and near the Cape of Good Hope, were from the southward and eastward. In the summer months, from April to October, these winds were generally accompanied by settled weather; but in the months of January, February, and March, they sometimes blew, for several days together, with such violence, that vessels were frequently driven out of Table Bay, with all their anchors down, and were unable to regain their anchorage, until the gale had abated. The chief danger, however, to shipping and to any breakwater in course of, and after, erection,

arose from the gales from the N.N.W. These occurred, occasionally, in the summer months,[1] but more generally, during the winter months of June,[2] July, and August. They were always accompanied by a heavy swell, the waves of which, from the configuration of the bottom over which they passed, assumed the character of heavy 'shoal-water waves.' The bay having a northern aspect afforded no shelter from these gales, to the vessels moored in the anchorage, and being exposed to the full force of the wind and the sea, they were generally driven on shore. During the time he was on the Cape station, it was a common occurrence, after a north-westerly gale, to see the beach literally strewed with wrecks.

The breakwater was required to prevent the recurrence of these disasters, and to afford shelter for receiving and discharging cargoes, during fresh breezes and moderate gales. To answer these purposes, the greater portion of it would have to be constructed in 6 fathoms, or 7 fathoms of water, or a short distance outside of the breaking point of the crest of the waves, in north-westerly gales. Looking at the model of the breakwater proposed by the Author of the Paper, and bearing in mind the volume and the peculiar character of the waves, the condition in which they would arrive at the proposed structure, the momentum and velocity with which they would be travelling, as well as the possibility of north-westerly gales occurring during the progress of the work, he could not but concur with the opinions which had already been expressed, that such a mode of structure was inapplicable. He believed, that even if the breakwater could be completed as proposed by the Author, so far from the waves being broken up, or neutralised by it, they would, to use a sailor's expression, 'go clean over it;' and that by the action of a succession of such waves, the entire fabric would be speedily reduced to the state of a dangerous shoal-water reef, in the entrance of the bay.

He would add that, perhaps, there was no branch of duty of a Nautical Engineer which required so much discrimination as designing a breakwater, in reference to the peculiar character and condition of the waves which it was intended to reduce, or neutralise. The character of the waves and the many modifying circumstances of each case, could only be properly studied in the locality. It was, therefore, not surprising, that the Author of the Paper had selected a somewhat unfortunate illustration of the efficacy of the new system which he proposed; and although Mr. Curtis felt

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[1] H.M.S. 'Sceptre,' of 64 guns, and several other large ships were driven on shore and wrecked, by a severe north-westerly gale in the month of November, 1799.

[2] The Dutch fixed the 10th of May, as the period beyond which it was not safe for vessels to stop in the bay. Vessels, however, ventured into the bay, in the winter months, for refreshment and for trading purposes, notwithstanding the risk of north-westerly gales.

confident, that such a breakwater would be unsuitable to Table Bay, yet, on the other hand, he felt bound to state, that he considered the Institution was under great obligations to the Author, for bringing forward the present Paper, as he could readily conceive, that there were other localities, where such a mode of construction might prove economical and efficient. So far, however, as Table Bay was concerned, he thought, that if an economical structure was proposed for simply neutralising the waves, a system of iron cylinders, or columns, as proposed by Mr. Brunlees, (M. Inst. C.E.,) if erected in detached sections, would be the most effectual.

In 1847, when the subject of defences and breakwaters was discussed before the Institution,[1] he had stated that, notwithstanding he had been employed by the Admiralty on coast surveys in nearly every part of the world, and had paid much attention to the subject of the character and action of waves, he knew of no uniform rule which could be laid down as to the best form and material for maritime works; but that the only safe course which the Engineer could pursue, was carefully to acquaint himself with the peculiar circumstances of the locality and the special character and mode of action of the waves with which he had to deal, and then to adapt his structure to the conditions of the individual case. Notwithstanding all that had been written and said, and the costly experiments made during the last eleven years, with the view of generalising certain special systems of construction, he was still of the same opinion. They were merely attempts to arrive at conclusions without a careful study of the premises; for it might be safely stated, that the comparative stability, economy, and duration, of any hydraulic work, would be almost, if not entirely, proportionate to the amount of knowledge and skill, which had been bestowed on the preliminary survey of the physical features, and hydraulic phenomena of the locality.

Amongst other sources of error, he included the present theoretical division of waves into the two classes, waves of the first, and waves of the second order,—or waves of translation, and waves of oscillation. However useful such a classification might be in the tentative processes of mathematical research, he contended it was comparatively useless as regarded practical execution. The term, 'great wave of translation' was, no doubt, well adapted to denote the great wave of the first order, or tidal wave, but he found that misconceptions arising from application of these terms to the wind waves of the ocean and sea coast had, in no small degree, contributed to the many crude and impracticable schemes which, from time to time, were brought forward as 'universal'

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. vi., p. 125.

modes of constructing breakwaters and sea defences. He thought, that all waves not occasioned by earthquakes, tides, currents, or other extraneous causes, should be called 'wind waves,' as being solely due to the immediate, or latent action of the wind. For subordinate classification, he suggested, that it would be better to use names which gave a definite idea of the genesis, antecedent history, and existing character of the wave, such as, 'active surface-wind waves,' 'shoal-water wind waves,' 'latent shoal-water wind waves,' 'ground swell,' &c. Indeed, the ordinary terms used by seafaring men, conveyed complete ideas of every detail connected with a wave, and by the combination of them, any wave could be minutely and correctly described. When it was further considered, that the use of these terms would, at all times, place the Engineer 'en rapport' with his nautical informants, it certainly seemed a pity, unnecessarily to depart from a nomenclature derived from experience, and improved and consolidated by long-established usage.

In aid of a classification of this character, he would submit the following division and definitions of the terms more generally used by nautical men.

CLASS I. ACTIVE WIND-WAVES, or waves rapidly generated by the active, or immediate force of the wind.

1. Catspaw.—The first ripple produced by the wind.
2. Wind Waves.—Small waves with an unbroken top, or crest.
3. Crested Waves.—When the wind had increased its force sufficiently to push over, or break the top, or crest, of the wave.
4. Sea.—An accumulation of several crested waves, with a larger crest of its own.
5. Heavy, or Mountainous Sea.—An accumulation of several smaller seas.
6. White Waves.—When, by a sudden squall, or the violence of the wind, they were broken and laid low, as fast as they were generated.

CLASS II. LATENT WIND-WAVES, or waves slowly generated by the previously exercised force of the wind.

1. Cross Seas.—When, by a change of wind, or other cause, two systems of seas were crossing each other.
2. Chopping Sea.—Formed by two systems of seas, crossing each other at acute angles.
3. Swells.—Extensive waves without crests, and often, without existing wind, generated by gales which had subsided, or had taken place in some other locality from which the swell had travelled.

CLASS III. SHOAL-WATER WAVES.

1. Breakers.—Produced by the active wind-wave suddenly breaking against the coast, or on detached shoals, or reefs.
2. Surf Waves.—Periodical waves, formed when the ocean wave of either class in its progress to the shore, suddenly encountered a continuous shelving bottom.
8. Ground Swell.—Produced when the ocean swell got into shoal water; it was generally without a crest.
4. Rollers.—Rolling waves generated when the ground swell, in its progress to the shore, encountered a long line of continuously sloping bottom.
5. Blind Breakers.—Waves rising suddenly at intervals, and breaking; so called, from their not being perceptible, unless watched for. They occurred over bars of channels, and were, no doubt, produced by the ground swell.

Apart from the question of the terms which had been adopted for the purposes of classification, the profession, he considered, were much indebted to the scientific men who had so ably investigated the mathematical theory of waves. It was pleasing to note, how frequently the conclusions at which they arrived, agreed with the every-day observations and experience of practical men. The little step, or hummock, suggested by Mr. J. Scott Russell as an addition to a sea wall, in the case of a surf wave, was the actual shape assumed under the action of the surf wave, by the 'pierre perdue' of the Madras Bulwark; and its correctness in principle was further borne out, by the lagoon configuration of the coast of Coromandel, and of Central America, localities where, probably, the heaviest surfs in the world existed. With reference to the surface, or ocean wind-wave, it was very remarkable how small an object was sufficient to break its crest and prevent its rolling onwards. The knowledge of this fact was most important, as the force of the wave was always concentrated in the onward rolling motion of its crest, and when once the crest was broken, the force of the wave was destroyed. In former days, the Mount's Bay boatmen, when caught in a gale, used to avail themselves of this property of the ocean wave. They made a kind of loose raft of their oars and spars, and hung on to it by a rope to leeward, with as much security as if they were at anchor; the crest of the wave was thus broken by the raft, instead of continuing its course and rolling over the boat. Covering the surface of the water with oil, also prevented the formation of a crest. The Esquimaux, who had a similar custom to the Mount's Bay boatmen, availed themselves, in addition, of this property, by attaching to their spars large pieces of blubber, or seal's fat, the oil which drained from it stilling the surface of the water; and by these means, their little kayacks were enabled to ride out, with

safety, the heaviest gales. Although the smallest boat might ride securely, if the crest of the wave was broken before it reached it, yet the safety of the largest ships was endangered when, from bad steering, or any other cause, they were struck by the crest. Under such circumstances, it was no uncommon occurrence for the vessel to have the whole, or the greater part of her upper works carried away, and the men and everything on her deck, swept overboard. In illustration of his previous remarks, he would add, that to call the 'active ocean wind-wave,' or 'sea,' which was the ordinary cause of this class of accidents, a simple 'wave of oscillation,' certainly did appear to him a misnomer greatly calculated to give erroneous ideas, in designing any special structure for the resistance, or neutralisation of this character of wave.

Mr. A. GILES said he did not think, that wooden breakwaters were adapted to deep water. They might, in some situations, be useful and economical, but he questioned their durability. The duration of timber, when not creosoted, was very limited. He had seen creosoted timber show but little signs of decay after ten years, but how much longer it would last, he was unable to say. The Author's model had a stone base, which showed, that he also did not consider a wooden structure adapted for a deep-water breakwater. It was evident, that the amount of water stopped by the gridiron breakwater, would be in proportion to the openings between the gratings; if these openings were of the same size as the solid intervening parts, he apprehended the water would go through, and form a wave of translation of nearly half the magnitude of that outside, although not so powerful. He concurred in the opinion, that if a breakwater of that kind was struck in an angular direction by a sea, the counterforts would receive the whole force of the blow. Instead of a series of counterforts, it would be better, he considered, to make the breakwater solid, with a larger quantity of an inferior material; this, with its great weight, would be superior, more economical, and more durable than a breakwater made of counterforts of squared blocks. With regard to the slope of the old breakwaters, he agreed in all that had been advanced respecting the convex curve; but he doubted whether the sections of the various breakwaters exhibited, were quite correct. Mr. Rendel had informed him that, at Holyhead, the sea within range of the heavy waves, had trimmed all the outer slope down to 6 to 1, but that in deep water, below the action of the waves, the stones rested at their natural slope of $1\frac{1}{2}$, or 2 to 1; so that he considered the convex form of the outer slopes of breakwaters, to be more the result of accident than of design.

Mr. HAWKSHAW, V.P., said that, assuming the high-water mark to be 50 feet from the bottom of the sea, a vertical line, a cycloidal line, or a line representing the slope formed by the sea, as at Holyhead,

would all be applicable for the purposes of a breakwater. The discussion resolved itself into two separate questions;—the theoretical question, or which was the best form of wall to resist a deep-sea wave,—and the question of cost, which often compelled the adoption of a less perfect form than that deduced from theory. He should prefer a vertical wall, if it could be built at the same cost as the others, for he believed it to be the best form, and not liable, as had been objected, to be breached, any more than the other forms he had mentioned. Engineers had, therefore, to consider which of the three forms should, under all the circumstances of each case, be adopted. A vertical wall, in 50 feet of water, would require about 2,000 feet of masonry per foot forward: but if stone could be cheaply obtained in the locality, a rubble breakwater, though requiring ten times the amount of material, might be less expensive. But where stone was scarce and dear, the latter plan would be inapplicable. He had recently examined the breakwater at Marseilles, in which a steep slope had been adopted, and the requisite vis inertiæ had been obtained, not by building a vertical wall, but by throwing blocks of béton, or concrete, weighing from 20 tons to 25 tons each, pell-mell into the sea, and by that means, a sufficient slope had been secured, to resist the shock of the waves. But each case would have to be considered separately, and a decision arrived at, not merely from a theoretical preference for any given form, but from a careful review of all the incidental circumstances which the Engineer would have to take into account.

Mr. J. Abernethy said, it was of the greatest importance to arrive at fixed principles, as regarded the forms of breakwaters. It had been urged, that local circumstances were so different, as to render it almost impossible to lay down any general rule on the subject. But although local circumstances might vary, the hydraulic laws which regulated the motion of waves were fixed and immutable: he thought, therefore, that a definite conclusion could be arrived at, as to the best form of breakwater; first, for the deep-water oscillating-wave, and secondly, for the shoal-water wave of translation, or percussion. With regard to the first, he conceived that the long rubble slope, say of 7 to 1, between the levels of high and low water, which converted the deep-water oscillating-wave into a wave of translation, was an error in construction, not only as regarded the original cost, but also as to the future maintenance of works. It must be obvious, that the long seaward slope was exposed, not only to the percussive action of the waves of translation, but also to the recoil of the sea, or what sailors termed the 'undertow' of the wave. The effect of this constant action must be the conversion, by attrition, of the face on the seaward side, into a mass of boulder stones, and after every storm those stones would be dis-

turbed and drawn out, and the slope lengthened. To preserve that portion of the work, it would be found requisite to pave the whole with massive ashlar pitching, which would have the effect of giving the waves still greater force upon the vertical superstructure. As to the question of cost, (an important consideration in the cases of Portland, Plymouth, and Alderney, where such enormous masses of rubble were required to form the mound,) he thought the vertical form of structure would be found to be the cheapest. But there were other circumstances under which he would prefer the long slope. In shallow water, with insecure foundations, he believed the cycloidal form to be the best. At Aberdeen, the pier head was first constructed as a vertical wall in shoal water, but the foundation being insecure, it fell, more than once, from the constant percussion, and the effect of the 'undertow.' The cycloidal, or long-slope form was then adopted, by which a gradual resistance was offered to the force of the waves, and the pier head had now stood the test of nearly half a century. But it appeared to be manifest, that for deep-water breakwaters, required to resist the simple oscillating wave, the vertical wall was the proper form of structure; it was also the most economical and durable. Whatever fault might be found with the Dover breakwater, on the score of cost, he believed it to be the best example round the coast, as regarded form, for a deep-water breakwater.

Mr. Brunlees had already expressed some doubts as to the capabilities of the structure proposed by the Author, and to the durability of timber for such a purpose in a warm climate. He then exhibited specimens of the hardest wood of Brazil, which had been in use on the coast of Pernambuco, one of them during one year, another for two years, and another for three years. They had all been very much attacked by the teredo. The same deterioration had taken place in situations a long way down the same coast, and there was little doubt, that it would also occur in Table Bay.

He had designed a cast and wrought-iron breakwater and pier, which he considered presented several advantages. By placing the piles zigzag, at an angle of 90°, the greatest strength was obtained, for resisting the impact of the waves from any direction. He proposed, that each pile should be provided with a Mitchell's screw, which, in sandy, or loose foundations, would take the form of a disc, hydraulic power being used for sinking, as in the Morecambe Bay Viaducts. On reaching stiffer soils, or where the foundations were altogether of stiff material, the piles could be screwed down in the usual way. The louvre boards could be readily screwed and cemented into the grooves, thus adding to the strength of the structure, and, from the spaces between the piles being short, cast iron could safely be used. The space between low water and

the ground being comparatively open, there would be little obstruction to the run of the tides, and hence, there would be little tendency to silting up inside the harbour. The cost in England for a breakwater, 40 feet above the ground line, and 15 feet wide, would be £53 per foot run; and the cost of a breakwater and pier combined, of the same dimensions, would be £63 per foot run; including the angle pile, which should be made of boiler plate and be filled with timber, all the other cast-iron piles being filled with concrete.

Mr. A. J. ROBERTSON said, that as the model with an opening below, exhibited by Mr. Brunlees, constituted a type of a class which had been much commended, he would point out what he conceived to be an error in the principle of these breakwaters. Any wave impinging upon such a breakwater, would be propagated through the space underneath, and thus there would not be still water within the harbour. The piles were so arranged, that there were re-entering angles; consequently, the momentum of a wave, instead of being distributed over the whole space between the piles, would be concentrated into the middle angle, thereby occasioning undue pressure at that point. Again; the breakwater was vertical and had louvre boards so placed, that they would divert the water, as it rose, from its natural path, and thereby produce considerable resistance. Mr. Scott Russell had spoken in favour of the cycloidal form of breakwater, because the wave would produce an equal pressure over the whole surface, but he did not state the mode in which he had arrived at that conclusion. He also said, that although the vertical form was highly desirable,—the true principle, in fact,—still he considered it had more to bear, and that there was greater risk of its being destroyed, than a wall which was on the top of a sloping foreshore. Mr. Robertson agreed with the Author, that the vertical form was the true principle, as laid down in his first Paper. With regard to the objection urged against the gridiron system, that the wave would be propagated through the openings, he believed it was impossible for a body of water which passed through the gridiron in detail, to produce a wave of any magnitude; at the most, it would only cause a number of small undulations, of no importance whatever.

Mr. BURNELL,—through the Secretary,—exhibited the section of a pile, said to have been creosoted, which was driven in one of the banks on the sea shore of North Holland, and had been, subsequently, attacked by the teredo navalis. This circumstance had attracted great attention, for it was considered to prove, that the process of creosoting did not protect wood from the attacks of the worm; and the Dutch Government had appointed a Commission to report upon the case. A cursory examination of the section would, however, suffice to demonstrate, that this particular pile had never been properly creosoted. Had a piece of timber of a similar description

been treated like the sleepers for the East Indian railways, it would have been thoroughly impregnated with creosote, even to the pith. The destruction of this pile, therefore, did not detract from the value of creosote, as a protection to timber from the ravages of the teredo; it simply established a prima facie ground of accusation against those who undertook to perform the process.

He was also desirous of calling attention to another circumstance, which might have a far more important bearing upon the solidity of works in sea water, than might be suspected. Green-heart timber had, of late years, been much used, because it was believed to contain some peculiar acid, or flavour, which rendered it distasteful to the boring worms, and conferred on it an immunity from their attacks. Now on the 28th of April, he had noticed, that the surface of a remarkably fine stick of green-heart timber, then lying in the West India Docks, had been deeply furrowed by a worm, resembling the lymexylon: the heart wood was untouched. This fact did not, of course, necessarily imply, that the green heart did not possess immunity from the attacks of the teredo; but it certainly appeared probable, that a wood, liable to be attacked by one class of boring insects, would also be liable to be attacked by others; and he thought, therefore, that before green-heart timber was more largely used for Hydraulic Engineering, some experiments upon its qualities ought to be instituted. Piles of this wood should be driven in places notoriously infested by the worm, such as Lowestoft, Gravesend, Portsmouth, &c., and they should be carefully watched.

Mr. John Bethell said, that an experience of about fourteen years had shown him, that where timber had been properly impregnated with creosote, to the extent of 10 lbs. of oil per cubic foot, it perfectly withstood the action of the worm. But contracts were sometimes issued for the erection of piers, or other marine works, within a given time, and the builders were obliged to take timber which might have been floating for years in timber ponds, and had become soddened with water. Now it was impossible to force 10 lbs. of oil per cubic foot into wood, the pores of which were completely filled with water; quantities of timber had, therefore, been sent out as creosoted, which had not been impregnated with a sufficient quantity of oil, and instances of failure had, consequently, occurred.

Having been engaged in diving operations, some time ago, he was able to state, that the action of the wave was usually confined to about 6 feet beneath the surface; and below that depth there was little, or no oscillation. He thought, therefore, that if the open portion of the breakwater referred to, was below the lowest part of the level of the wave, it would not be propagated on the other side.

In answer to questions from Members, Mr. Bethell said, that his

diving operations had been carried on, at different places round the coast of England, and he had invariably observed, that there was very little oscillation just below the hollow of the wave. The operations were sometimes continued in rough weather, yet the waves had no effect upon the air pipes and signal lines below.

Mr. J. Cockburn Curtis considered, that the action of a wave upon the bottom, depended materially upon the age of the wave, and the other circumstances under which it arrived in the locality. Those who had been much employed in sounding, dredging, coast-line examinations, and the other details of marine surveying, saw in the different objects brought up by the dredge, the heavy bodies which were sometimes cast on shore; and the circumstance of submarine shoals and banks, at great depths below the surface, being occasionally perceptible by the increase of the wave action immediately above them, gave evidence of a disturbance to a much greater depth than that stated. He believed, that in the cases which had been cited, when the disturbance was confined to a small depth, the 'active wind-wave' was that which had existed at those times, and not the ground swell, or 'latent wind-wave.' So far as he had been able to observe, the action of a wave upon the bottom, did not depend so much upon the height of a wave, as upon its volume, and the expanse of surface over which it was diffused.

His previous remarks appeared to have been misunderstood. He did not absolutely condemn the principle of the structure proposed by the Author of the Paper, but he had endeavoured to show, that it was inapplicable to the neutralisation, or resistance of waves of such a character as those which entered Table Bay, during the north-westerly gales. The proposed structure might, no doubt, break smaller waves, if they were of great height in proportion to their volume.

Mr. Bidder,—President,—remarked, that there were a variety of ways in which an efficient breakwater could be constructed, but the great desideratum was to find an efficient method of construction, more economical than the systems hitherto employed. The first datum required was the bonâ fide cost of existing breakwaters; he hoped, therefore, Mr. Cooper could give the Meeting some information as to the cost per yard, or per foot, of the Alderney breakwater, at the present depth of 20 fathoms of water. The works there, were carried on economically, so far as the carriage and placing of the material was concerned.

Mr. James Cooper said, he was not prepared, at that moment, to give the cost of the Alderney breakwater; he could only state, that the works were now being carried on in 21 fathoms of water, and the cost was found to increase in proportion as the depth became greater.

Mr. John Murray agreed with the President, that the ques-

tion was, above all, one of cost. There were, of course, various methods of constructing breakwaters, but the system to be adopted depended greatly upon the locality. It was requisite to take into consideration the action of the tide, the direction of the prevailing winds, and the force with which the waves would strike the breakwater. Now, there was a very powerful sea running round the Cape of Good Hope, and the force exerted by those tremendous rollers, in very deep water, was evinced, by their stirring up the sand bank off the Cape; no ordinary structure, therefore, would be of any use in that locality. But breakwaters were generally placed in a more sheltered position, either in bays, or in shallow depths. The water at Alderney was about the deepest in which a breakwater had been, hitherto, constructed. At the discussion upon the Author's first Paper, Mr. Murray had gone into the question of cost,[1] from which he had arrived at the conclusion, that the cheapest method of construction was to form a deposit of stone from the bottom, to a certain distance under low water, varying from 6 feet to 15 feet. He did not approve of the practice of using the stones taken from the quarry, indiscriminately, and putting into the heart of the breakwater the large stones mixed with the small ones, as had been done in several of the breakwaters already completed. He thought it would be preferable to make a nucleus of small stones at the bottom, where they could not be affected by the action of the waves, to cover them with large stones, gradually increasing in size, up to about a depth of 12 feet at low water, at a slope of 2, or 1½ to 1, and in some cases of 1 to 1, and then to commence the superstructure. Now it was the latter that was the great source of expense, when carried out, as had been, hitherto, the practice in this country. A lesson in this respect might be learnt from the French. At the breakwater at Algiers, large blocks, many of them weighing from 10 tons to 15 tons and 25 tons, were used from the very bottom. They were manufactured on shore, where they were allowed to dry; they were then placed upon a railway and tipped over the end of the breakwater into the sea. At Marseilles, on the contrary, the plan he had just recommended had been adopted; gradually increasing the size of the blocks to a certain height, when blocks of béton were used as an outer covering. The breakwater at Marseilles was in a depth of water from 5 fathoms to 7 fathoms, and had cost about £215 per lineal yard; it was the cheapest structure, he believed, of the kind ever erected. At Algiers, where large blocks were used at the bottom, where labour was dearer, and the warmth of the climate impeded the progress of the work, the cost had been £360, or £370 per lineal yard. The depth of the works there

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xviii., pp. 105 *et seq.*

was 7 fathoms. Of late, the system had been altered at Algiers; large blocks were now no longer used, till the structure had been raised to within 20 feet of the surface, with small stones. There was considerable saving by this method of throwing in artificial blocks, in large masses; one-third of the cubical section of the breakwater might be deducted for the interstices between the blocks, and these interstices were also valuable in another way. They allowed of percolation taking place through the structure, and they were filled up by the sand, which cemented the whole into one solid mass. They were also valuable in the upper portion of the work, by allowing a passage for the waves, and thus stilling the water inside the breakwater. In constructing harbours of refuge, the main object was to break the great force of the waves, and to endeavour to secure smooth water within, so as to enable trade to be carried on in the interior harbour, alongside of quays. A large superstructure, therefore, was not required, and there were many advantages in keeping it low; if raised to the level of high water of equinoctial spring-tides, the waves would roll over, and create an agitation in the interior of the harbour, which would prevent its silting up. In a military point of view, such a low breakwater would act as a glacis to vessels of war inside, which could deliver their fire over it, and yet be protected by it, to a great extent, from an enemy outside the harbour.

With regard to the plan under consideration, in which the superstructure was to be made with a series of counterforts at a slope of 2 to 1: if the rise of tide was 20 feet, the length of each of the counterforts would be, necessarily, 40 feet. It was proposed to place them 20 feet apart, and if they were 10 feet in width, the distance would be 30 feet from centre to centre. Now the cost of erecting such counterforts would be enormous, because they must be built by manual labour, and be sufficiently strong to withstand the shock of the sea. The expense would be the same as that of a pier with two faces, at a distance from each other of 20 feet, and would be greater than building two longitudinal walls. It was then proposed to connect the counterforts by iron girders, with the view of producing still water within. But a heavy wave striking the gridiron surface, spanning the interval between the counterforts, would have a greater tendency to run upon the work in a body, than to pass through the intervals of the grating.

It had been stated, that there was no agitation from waves, below a depth of 6 feet from the surface. Now at Sunderland, he had considerable experience in diving-bell operations during twenty-five years. On going, one day, to the works at the north pier, where the diving bell was usually in operation at a depth of 20 feet, for cutting off the piles, he was astonished not to find it at work, as the day was calm, and there was but a slight roll on the surface of the

water. Upon making inquiry, he was told, that the bell had been let down, but the water was found to be so much agitated, that the men could not work. To verify this he went down himself, and from the rolling of the bell he was soon convinced, that it was impossible to work without danger. The cause was soon discovered, for, two, or three tides afterwards, there was a tremendous rolling sea and a storm from the north-east. It appeared, that there had been a storm in the Atlantic, on the west of Scotland, which had agitated the water at the bottom, and had carried forward the agitation to the North Sea, between Scotland and Norway, and round the English coast, to Sunderländ. This action of the sea at considerable depths, was still more prominently brought under his notice in another way. In the coal trade, the ballast of the vessels returning to the north, which sometimes consisted of chalk and flints, was usually discharged at a distance of from 7 miles to 10 miles from port, instead of 5 miles as formerly: yet after a violent storm, the whole coast was strewed with ballast which had been cast into water, 10 fathoms, at least, in depth, and the flints were easily recognised as coming from the Thames.

Mr. M. Scott said, it had never been his intention to propose the employment of timber at Table Bay, but exclusively stone and iron. With reference to the statements respecting the magnitude of the waves, and the great ease with which they would pass over this structure, he remarked, that as the model he had exhibited was very small, it had tended, perhaps, to give erroneous ideas of the actual dimensions of the work itself. It was 80 feet in height, and the superstructure was 80 feet in width; and he could not conceive, that a large wave could pass over a structure of that size, with such facility as had been suggested. But if 80 feet were not sufficient, the dimensions might be increased to 100 feet, or even 120 feet, and the cost of the structure would still be less than that of any other form of breakwater. He might be permitted to congratulate the Members, upon the progress this subject had made since he had presented his former Paper. There seemed now to be very few dissentients from the principle of the vertical wall, which, on that occasion, was very much disputed; but the main objection to it now, was the great cost it involved. He concurred in the remark of the President, that cost was the question which must, eventually, determine the form and method of construction of every breakwater; it was, therefore, important to show that, in this respect, the vertical wall had the advantage over every other form, hitherto applied. He believed, as he had endeavoured to show in his previous Paper, that it was possible to construct a breakwater with a vertical face, by employing, in the first instance, timber work, and subsequently, facing it with large blocks of stone, at less cost than any of the sloping forms.

The principle of the proposed structure had been tried on a small scale, and found to be successful. The undulation of the wave was destroyed, and the water passed through the breakwater, in something like a stream; there was a broken surface, but no undulation, and no wave. He had suggested this form precisely, because, in such a situation as the Cape, there were, evidently, great difficulties in applying any of the ordinary forms of breakwaters, and the waves were very heavy. The supposed difficulty with regard to the counterforts had arisen, he thought, in consequence of the details of that portion of the structure not having been given; but the way in which they were proposed to be constructed, would show, that the expense would not be great. They were supposed to be constructed of large and heavy blocks of rubble, cemented together, and so interlocked, that each counterfort should become one whole mass. He was quite satisfied, that the cost of the work would not exceed the sum he had stated. The forms adopted at Plymouth and Portland would not withstand the force of the waves at the Cape; and he thought the plan he had proposed, was the only one capable of dealing with such great masses of water.

Mr. Scott Russell appeared to think, that these great rollers could only be broken by opposing mass to mass. If that principle were recognised in the case under consideration, the mass must be very great to oppose such waves as these, and necessarily, be very expensive. He proposed to place before the breakwater a detached mass of rubble stone, at a considerable distance seaward, and parallel with the breakwater, in order to destroy the wave. This, no doubt, would be the effect, but, practically, it was tantamount to constructing two breakwaters. He also advocated the system of projecting a very long foreshore; the effect he anticipated from it would inevitably result, but it could only be obtained at excessive cost.

It had been objected, that the water passing between the girders, would strike the counterforts obliquely, and that they would receive the whole force of the blow. But that assumed, that the sea came nearly end-on to the breakwater, which could never be the case; and even if this were possible, counterforts of solid masonry, 12 feet in thickness, were not likely to be destroyed by the water that would pass through spaces, 20 feet in length, and 1 foot in breadth. The only surface exposed to the blow of the wave would be of iron, and the girders would be capable of supporting the pressure of 100 feet of water. It was also objected, that the water would press through the openings and produce a wave inside the breakwater. He dissented from that view, for the worst that could happen would be for the water to pass through a number of the spaces at the same moment, each

producing a wave; but even in that case, the waves would be small, and by their succession, they would neutralise each other. The misconception arose from considering a sloping screen, with horizontal bars, to be the same as a vertical screen with vertical bars, and ignoring the fact, that whereas, in the latter, the water passed through at the same moment, leaving the continuity of the wave unbroken, in the former it passed through in detail, and at successive periods of time, whereby the continuity was destroyed. The principle of a screen with horizontal bars had been tried on a small scale, and had been successful; the wave was entirely broken: if the bars had been placed vertically, he had no doubt it would not have been destroyed. The only forcible objection that had been taken to the new form was, that the wave might go over the top of the slope. Now it was evident, that the whole would not go over, under any circumstances; the quantity would entirely depend upon the magnitude of the work. But if a slope 80 feet in width was not sufficient to prevent it, it could be extended to 100 feet, or to 120 feet; and even then, it would only cost £126 per foot run, which was less than any other form equally effective. The breakwater could first be built 80 feet in width, and any addition could be made afterwards. Every addition to the efficiency of a vertical wall, by increasing the height, diminished its strength, whilst every increase to the efficiency of the proposed work, added to its strength, because every foot added to the height, involved an increase of 2 feet in the width.

With respect to the breakwater at Blyth, alluded to in the Paper, there had been some misconception regarding the principles upon which it had been constructed. The straight part of this portion of the work was so like, in external appearance, some other works, that it had been assumed by many to be similar, whereas in principle and action it was quite different. The fundamental idea had been, that the work should rest on, and not be attached to the ground; but that its stability should be entirely dependent on the weight of the stone filling, and be independent of any ground fastening. The second object was so to combine the timber and stone, that they should form one whole. Both these objects had been effected, but it must not be forgotten, that an apparently slight change in either the form, or in the details of construction, would be attended with great danger to the structure. There were several other peculiarities in that work, one being the great facility afforded by the system of framing the timber on shore, and depositing it complete in its place. He thought it necessary to make these observations, because this system of construction was being adopted elsewhere, and if attention was not directed to these details, apparently unimportant, but in reality involving principles, success could not be expected.

He feared that his observations respecting some of the existing works, had been construed into reflections upon the Engineers who constructed them; this he exceedingly regretted. In introducing any new system, the only means of fairly bringing it under notice and criticism, was to compare it with examples, where other systems had been applied. This was all he had intended to do; and it could scarcely be regarded as reflecting upon the Engineers engaged, to point out, that works constructed many years ago, were not executed upon principles which had only recently been recognised.

Mr. Bidder,—President,—said, that in this case, the Institution had departed from the usual rule of abstaining from the discussion of projects, and he thought some inconvenience had been occasioned thereby. The discussions were generally confined to works that had been already tested and tried; and the great difficulty in considering the subject of breakwaters was the absence of important facts concerning them, for the whole question, after all, mainly turned upon the cost, which must be dependent on the peculiarities of the various localities and the materials which they afforded. The breakwaters at Holyhead, Dover, and Alderney, could not be expected to be constructed at the same cost as that at Portland, where there was an inexhaustible supply of stone. He was, personally, inclined to doubt whether, granting all the positions assumed by the Author of the Paper, the wave screen would be an efficient breakwater in any situation, and whether any real economy would result from its use. It certainly could not at Alderney, or Portland, or Holyhead: it might, possibly, be applied at Dover, but even of that, he was very doubtful. But the advisability of introducing this breakwater must depend, in a great measure, like all other questions of engineering, upon the confidence which capitalists reposed in the Engineer. The question of breakwaters still remained in a very unsatisfactory position, and Engineers had been unreasonably blamed for it. At Alderney, within the last year, a first-class frigate had struck upon an apparently unknown rock in the centre of the harbour. This, certainly, was not the fault of the Engineer; but it did reflect, and not very creditably, upon some department, or another. With regard to Alderney, he thought the Author of the Paper had not mastered all the peculiar features of that locality. The sea rose there in a most peculiar manner. Mr. Rhodes, the late Resident Engineer of that work, had told him that, on one calm day, when he was at the end of the breakwater with Captain Washington, they saw a swell coming from the north-west. Mr. Rhodes advised Captain Washington to retire as quickly as he could, yet before he had left the pier, the sea was already making a breach over the end of it. In such a situation he thought, if there was to be a breakwater at all,—a question which could not be dis-

cussed at this Institution,—there was scarcely any choice, and that the mode now adopted was the only one likely to be effectual. He hoped Mr. Cooper, would, on some future occasion, be able to give the information for which he had asked,—the cost per yard of the walls in 20 fathoms of water, at Alderney, where the stone had to be quarried by the Contractor, as contrasted with the cost in 10 fathoms of water, at Portland, where the stone was quarried by convicts. He believed it would be found, that at Alderney, the quarrying cost less than at Portland. If such should prove to be the fact, it would serve still further to demonstrate the advantage of ascertaining the whole of the circumstances attaching to each case, even when the actual cost was known; for there was no apparent reason, why the works at Portland should not be constructed as cheaply as those at Alderney. The Institution had no data upon which to arrive at a satisfactory conclusion. With respect to breakwaters, he considered, therefore, that the profession was fairly entitled to ask, that those Engineers who were employed in constructing important national works, which were paid for out of the public exchequer, should be called upon to furnish detailed particulars, in reference to their cost, and the mode in which they were carried out.

MEASUREMENT OF GAS.

It was announced that a Paper had been received, which would, probably, be read, early in the ensuing Session, "On the Measurement of Gas, and the Classes of Gas Meters, in general use," by William Crosley, Assoc. Inst. C.E.

This Paper stated, generally, the facts connected with the early introduction of gas lighting, and its progress, up to the present day, when the rental amounted to about five millions of pounds sterling per annum,—and the consumers, to several millions of persons, supplied by upwards of one thousand companies, corporations, or private proprietors of gas works. With a view of ascertaining the quantity consumed, otherwise than estimating by burner, the gas meter was introduced by Mr. Clegg, (M. Inst. C.E.,) and the late Mr. Samuel Crosley. After this instrument had been in use for some time, it was found that, although it had been considerably modified by other persons, it could not always be relied upon for correct registration. The general complaints from the consumers of gas led to the passing of an Act, in the last Session of Parliament, to insure a more constant inspection of the instruments for measuring gas. The details of a series of experiments on meters

of various designs and construction were given, showing how great an amount of error prevailed. At the same time, remedial measures were pointed out, and discussion was invited upon the best instruments for use, and the most effectual systems of supervision.

At the conclusion of the last Meeting, Mr. BIDDER,—President,—said, he would take that opportunity of congratulating the Members, upon the proceedings during the Session which had now, practically, terminated. The finances were in a flourishing condition, many new Members and Associates had been admitted, and the attendance at the Meetings had been, at least, equal to, if it did not actually exceed the usual average. The future prosperity of the Institution depended upon the Members and others, contributing Papers upon subjects, not only of interest to the profession, but to all who were engaged in scientific pursuits.

June 5, 1860.

The Session was concluded by a CONVERSAZIONE, at which the President received the Members of the Institution, and a numerous circle of distinguished visitors. The rooms were decorated with many choice works of art, and there was also exhibited a large and interesting collection of mechanical models.

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